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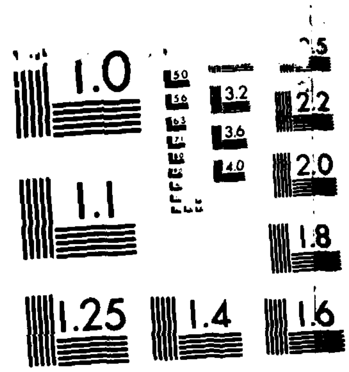

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PRELIMINARY DESIGN FOR DISPOSAL OF DREDGED MATERIAL FROM THIMBLE SHOAL CHANNEL ON WEST OCEAN VIEW BEACHES

NORFOLK, VIRGINIA

BY

Waterway Surveys & Engineering Ltd.
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FINAL REPORT

JUNE 1984

Prepared for:
Dredging Management Branch
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Report recommends specific areas of Thimble Shoal Channel that contain sediment (sand) suitable for beach nourishment along West Ocean View beaches. The eroded beaches need a restricted amount of sand for most efficient use of the existing groins. Report suggests that well-planned measurements of tidal currents near the Ocean View shore would be helpful in assessing the importance of longshore transport by tidal flows. Also, bathymetry and topography within groin compartments must be known in order to determine what reserve storage capacity exists, and what dredged material volume will be suitable.

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EXECUTIVE SUMMARY

Sandy dredged material from a segment of Thimble Shoal Channel can be disposed of usefully at beaches along Willoughby Spit and vicinity, if navigation channel dredging were authorized to -55 feet. The delineated channel segment above -55 feet contains 850,000 cubic yards of moderately coarse quartz sand. This channel segment extends for three miles in the eastern half of Thimble Shoal Main Channel, including the Chesapeake Bay Bridge-Tunnel crossing. It is recommended that the sand dredged from the designated channel area be stockpiled until needed at a submarine site about 2 miles ENE of the beach disposal area.

The recommended design profile for disposal includes a backshore elevation of +5 feet MLW and an equilibrium foreshore slope of 1 on 8. Design profiles are of two types, an east profile and a west profile. Both overfill and durability factors indicate that designated dredged material is fairly suitable as beach fill. At most, 500,000 cubic yards of channel material would be an appropriate fill on Willoughby Spit. This quantity would initially advance the shore between 80 and 150 feet along the 4200 yards of eroded coast; after reworking, the disposal is expected to result in a relatively stable shoreline about 50 feet seaward of the present location. However, since the native sand is about a half a millimeter in diameter but the dredged sand is about a third of a millimeter in diameter, initial losses could be high. On the other hand, to compensate by overfilling so that the new material buries and extends seaward of the existing groins could be wasteful of material.

The delineated channel segment is based only on three cores, all located south of the channel centerline. The continuity and extent of the assumed sand deposit needs to be verified.

PREFACE

This report summarizes engineering work performed to investigate the feasibility of using dredged material for beach fill on West Ocean View Beaches at Norfolk, Virginia. The potential source of dredged material would be sediments in Thimble Shoal Channel made available through planned harbor deepening. The benefits derived through such utilization of dredged material appear to be profound.

This study and related engineering work were performed under Contract No. DACW-65-84-D-0054 by Waterway Surveys and Engineering, Ltd. (WS&E) for the Dredging Management Branch, Norfolk District, Corps of Engineers. The work was coordinated by Mr. Richard Klein, Project Engineer.

The firm of Cyril Galvin, Coastal Engineer performed as a consultant and participated in both field investigation and engineering analysis.

The report was prepared by Robert Hallermeier, Jonathan W. Lott, Cyril Galvin, and James W. Holton. The field work was carried out under the supervision of W.C. Holton, and technical engineering support was provided under the supervision of John Walsh.

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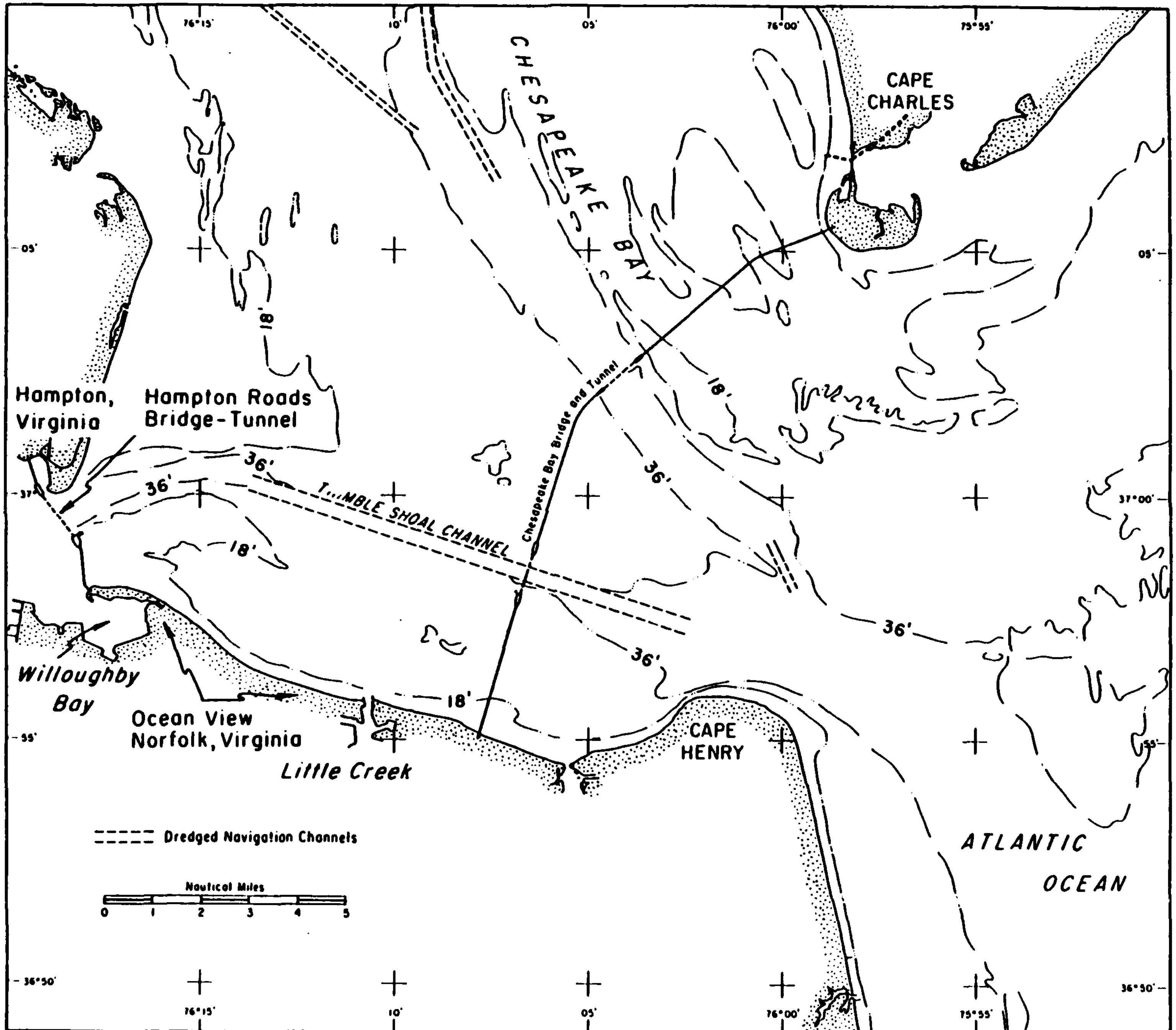
PRELIMINARY DESIGN FOR DISPOSAL OF DREDGED MATERIAL FROM THIMBLE SHOAL CHANNEL SANDS AT WEST OCEAN VIEW BEACHES, NORFOLK, VIRGINIA

INTRODUCTION

In plans for deepening Thimble Shoal Channel within lower Chesapeake Bay, one important topic is the potential use of dredged material as beach fill on nearby shores, because such local disposal of suitable sediments may have beneficial uses. This report evaluates the feasibility of disposing Thimble Shoal Channel sand on beaches immediately southwest of the Channel on the Chesapeake Bay shoreline of West Ocean View, Norfolk, Virginia. The shore segment of primary interest is the three miles of beach along Willoughby Spit, directly south of the naturally deep passage linking Hampton Roads with the Chesapeake Bay and Atlantic Ocean. Figure 1 shows the Chesapeake Bay entrance with the region of interest near the western limit to the South Bay shore.

The major following sections treat these topics: extent and characteristics of potentially suitable sediments in Thimble Shoal Channel; features of the beach and nearshore zones in the study area along West Ocean View, according to previous investigations and 1983 field work; review of available environmental data, presentation of some computations, and an overview of important processes in southwestern Chesapeake Bay; and engineering considerations relating to disposal on Willoughby Spit of Thimble Shoal



Taken from NOAA Chart 12221 (Jan 1982)

Figure 1. Map of Chesapeake Bay entrance with relevant sites and depth contours.

Channel dredged material. The final report section summarizes conclusions on disposal feasibility and recommendations for advisable further investigations.

Three additional introductory points are important. This report considers Thimble Shoal Channel sand additional to that considered for disposal at Fort Story, Virginia, in a prior report (Hallermeier, Lott and Galvin, 1984). An extensive groin system along the West Ocean View coast strongly influences shore processes, and a design for durability must be consistent with the existing groin geometry. Another engineering consideration addressed here is the possibility of a marine stockpile for dredged channel material not immediately usable as beach fill.

SEDIMENTS IN THIMBLE SHOAL CHANNEL

Thimble Shoal Channel is presently 9.9 nautical miles long, with its eastern end at the naturally deep main entrance to Chesapeake Bay, just north of Cape Henry, and its western end at the naturally deep entrance to Hampton Roads, north of the western section of Ocean View, Norfolk, Virginia (Figure 1). The authorized project consists of a main channel 1000 feet wide with nominal water depth of 45 feet MLW, and flanking auxiliary channels each 450 feet wide with nominal water depth of 32 feet MLW. This section identifies sediments usable as beach fill to be obtained by anticipated deepening of the Main Channel.

During June 1983, cores of bottom sediment were obtained at 42 sites in and near Thimble Shoal Channel. Figure 2 presents a simplified schematic summary of bottom materials in 28 cores along the Main Channel. Each core is

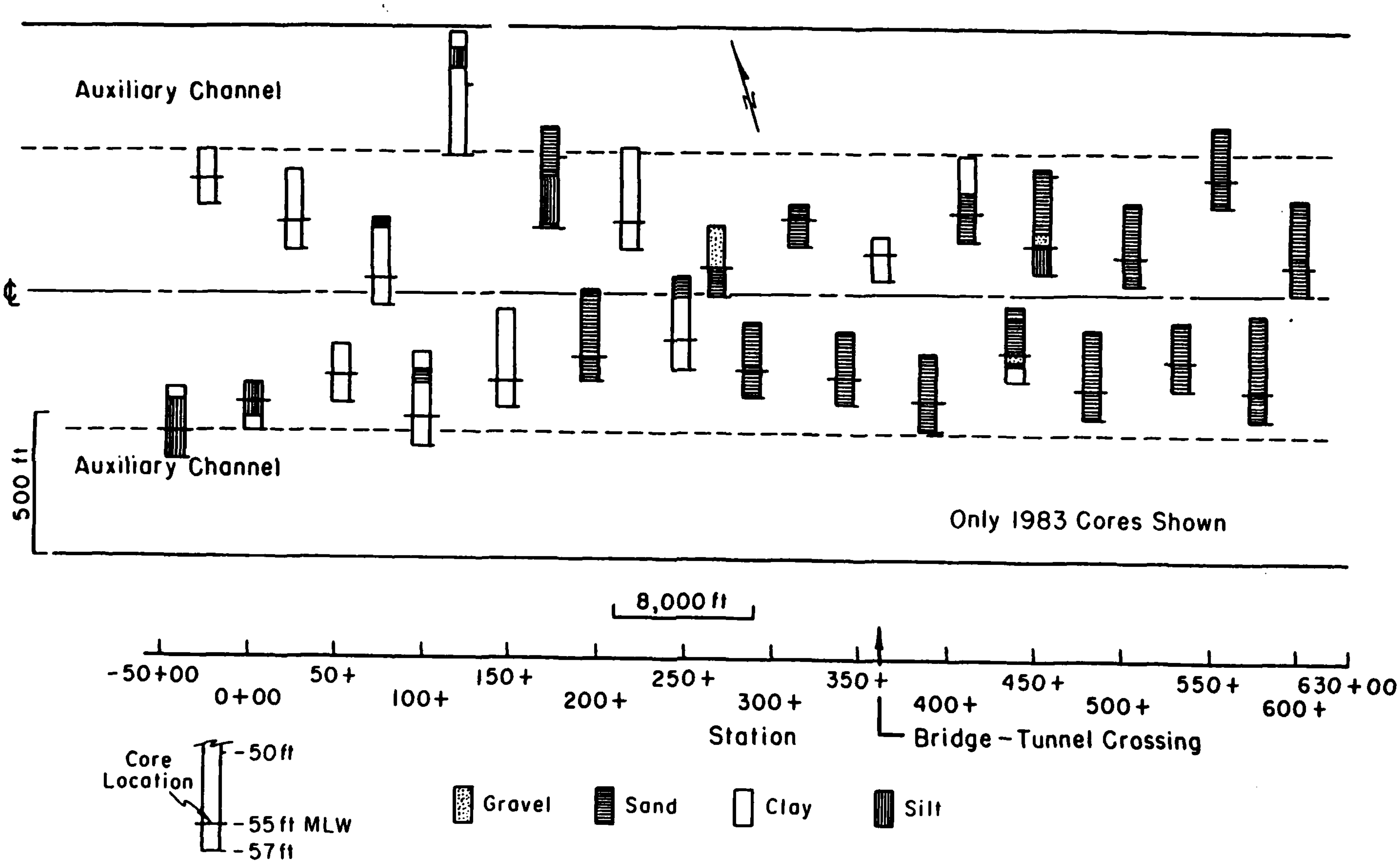


Figure 2. Bottom materials in 28 cores of Thimble Shoal Main Channel. Cross-channel scale exaggerated 16 times.

depicted to scale from -57 feet MLW up to the core top, i.e., the local water depth. Soil types are distinguished according to primary soil types only (gravel, sand, clay, or silt), so that many perceptible differences recorded in core logs are not depicted on Figure 2.

The channel bottom is above -50 feet MLW at only four of the 28 core sites. The bottom material is predominantly clay near the western end of the channel, but almost entirely sand at the eastern end. In between, from stations 160+00 to 470+00, all types of materials occur at various elevation. However, for these intermediate locations, beach disposal may be attractive because they are closer to Ocean View Beaches than is the eastern end of the channel.

The anticipated depth limit to dredging (including allowable overdredging) is extremely important in identifying usable dredged material. Table 1 summarizes computations and judgements on potential sand dredging in Thimble Shoal Main Channel, for four possible dredging depths. The depth selection affects the optimum location for dredging of appreciable sand volume over a continuous area, as the appropriate extent and relative ranking of candidate sediment locations can change. Final designation of an appropriate channel dredging area for beach disposal depends on the match of size characteristics to native beach sediment, as described later in this report.

A prior report (Hallermeier, Lott, and Galvin, 1984) considered disposal of Thimble Shoal channel dredged material on beaches at Fort Story, Virginia, and concluded that the channel area designated "Z" on Figure 3 has sediments that are nearly ideal for Fort Story beaches. Figure 4 displays the composite grain-size distribution for material

Table 1. Summary of prospective dredging and potential beach disposal volumes from Thimble Shoal Main Channel. Computations based on analysis of 1983 core data.

Limit To Dredging, feet MLW	Tentative Amount, cubic yds	Overall Classification of Material	Locations of Sand within Main Channel: Estimated Volumes and Materials	Core Numbers
-50	630,000	45% sand 20% silt 35% clay	200,000 cubic yards of sand near station 169+00 and north of centerline	43
-52	2,900,000	55.5% sand 6.5% silt 38.0% clay	800,000 cubic yards of sand between stations 430+00 to 600+00 across entire width of Main Channel	54 through 61
-55	8,900,000	54% sand 4% gravel 6% silt 36% clay	1) 2,700,000 cubic yards, 97% sand and 3% gravel, between stations 430+00 to 600+00 across entire Main Channel	54 through 61
			2) 1,000,000 cubic yards of sand between stations 270+00 to 430+00 and south of centerline	48, 50, 52, 54
-57	13,400,000	52% sand 3% gravel 8% silt 37% clay	1) 1,400,000 cubic yards of sand between stations 270+00 to 410+00 and south of centerline	48, 50, 52
			2) 2,900,000 cubic yards, 98.4% sand and 1.6% clay, between stations 465+00 to 600+00 across entire main channel	56 through 61

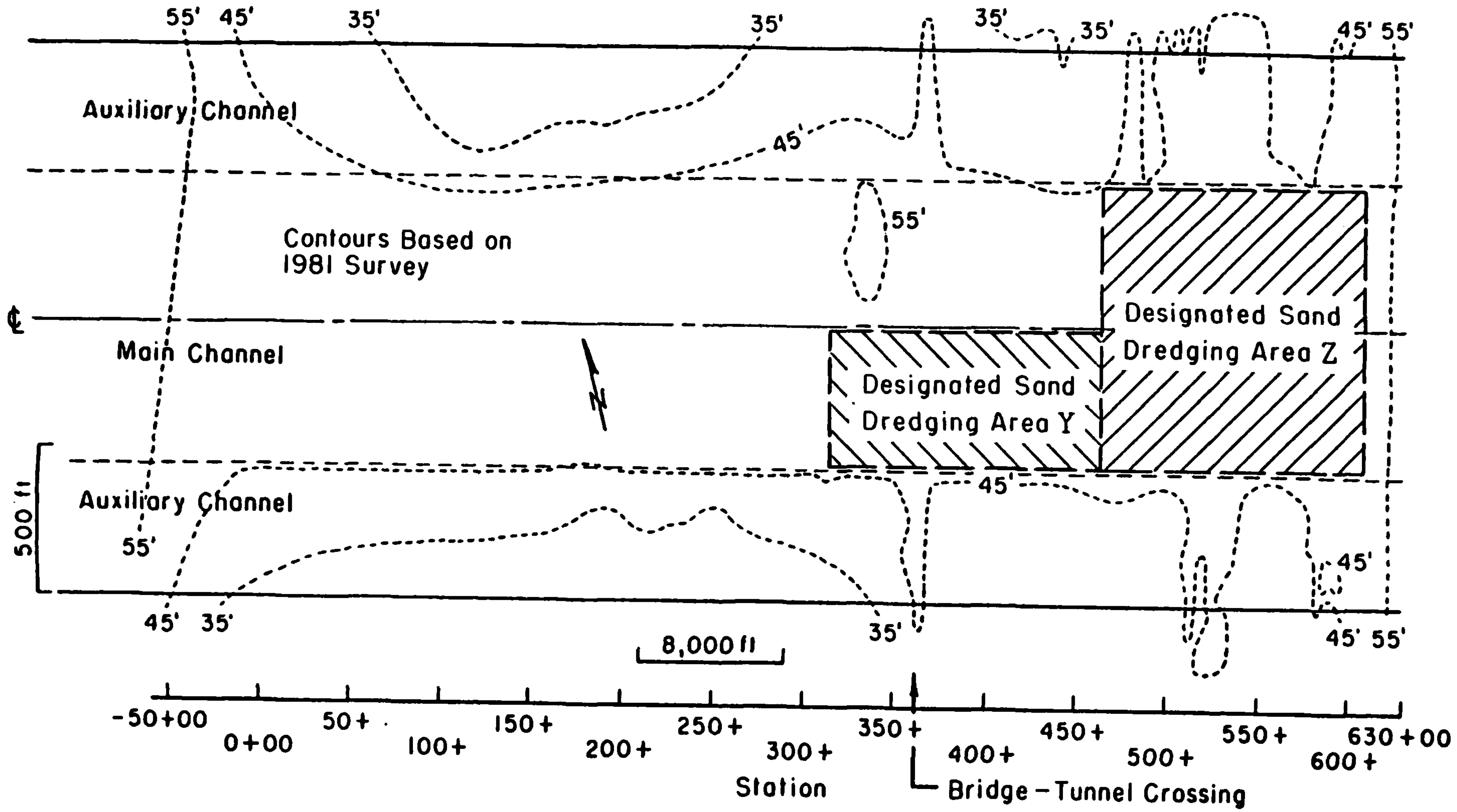


Figure 3. Designated dredging areas in eastern half of Thimble Shoal Channel.

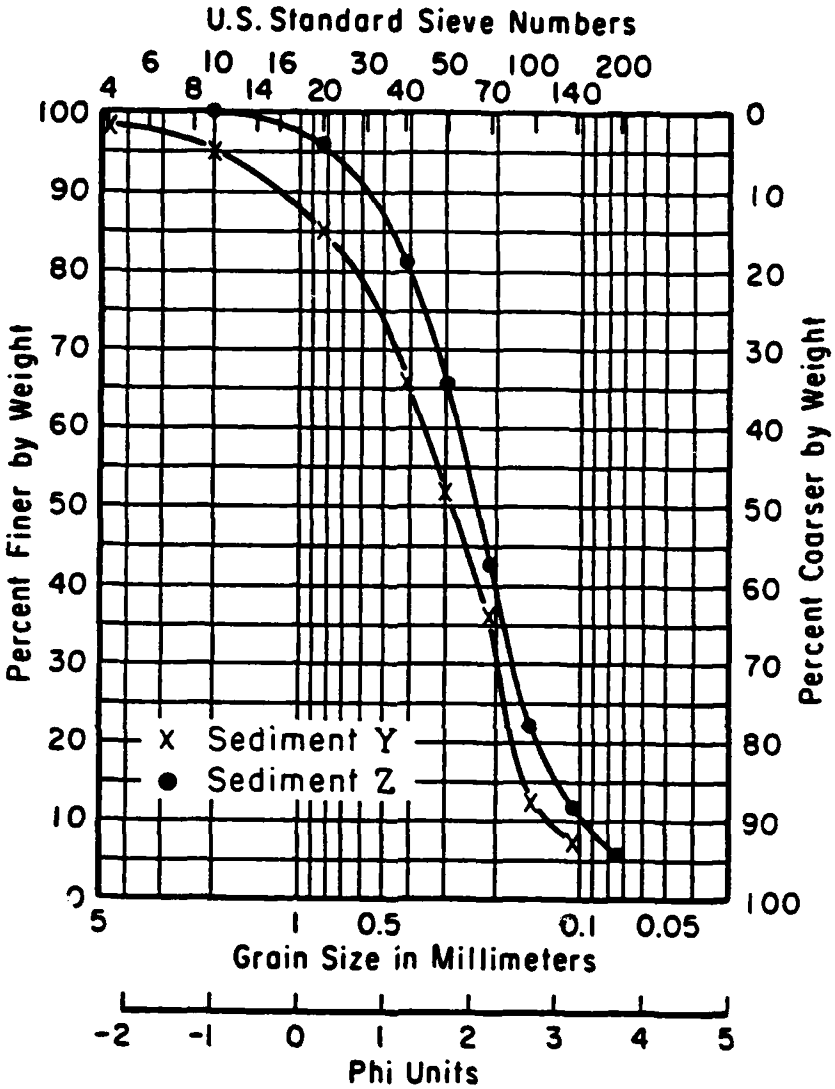


Figure 4. Composite grain-size distributions for the two dredging areas of Figure 3.

above -55 feet MLW within Dredging Area Z. Using that same -55 feet MLW depth in this Ocean View study leads to the area designated "Y" on Figure 3 as a promising source of suitable material (see Table 1). Dredging Area Y is defined by three adjacent cores, and the representative composite grain-size distribution is curve Y in Figure 4 (computations in Appendix A). Sediment Y is noticeably coarser than Sediment Z. Appendix A develops the estimate that about 850,000 cubic yards of Sediment Y sand extend above -55 feet MLW between stations 315+00 to 465+00 in the Main channel south of the centerline. Dredging Area Y is approximately 8 nautical miles from the Ocean View beaches under study here.

Available evidence makes it unlikely that appreciable quantities of sand are available from the dredging of the western half of Thimble Shoal Channel (west of Station 300+00). Ludwick (1979) reports "... a definite break in the character of the sediment at approximately 323+00 ... Sands are found seaward of this point and silty clays occur landwards." Ludwick's (1979) break is fairly consistent with the new core data summarized in Figure 2. Clay is predominant west of 250+00 (and more common north of the centerline). Figure 2 supports a distinction between the southern and northern sides of the channel centerline and suggests that additional coarse material may be located between 250+00 and 350+00 north of the centerline. Although additional data are needed, available information indicates that Dredging Area Y on Figure 3 should be regarded as a promising source of relatively coarse dredged sand.

OCEAN VIEW COASTAL AREA

Previous Studies. Fleischer, McRee, and Brady (1977) reported data and conclusions on the physical processes acting along the Ocean View shore, from the west end of Willoughby Spit to Little Creek Inlet about 7 miles east. Ludwick (1979) analyzed the magnitudes and patterns of bathymetric changes in lower Chesapeake Bay, and related those changes to shore effects between Willoughby Spit and Cape Henry about 16 miles to the east. Those two reports summarize some significant factors affecting Willoughby Spit. The detailed site map for southwestern Chesapeake Bay in Figure 5 displays local features important to this summary of previous studies.

Fleischer et al. (1977) offer the following background information. Indications are that the southern Chesapeake Bay coast "... originated by spit building and shoreline straightening of an irregular, marshy, lagoonal coast ... approximately one to three thousand years ago." At the present western terminus to this littoral cell, Willoughby Spit apparently became an identifiable feature rather suddenly, around 1800. It has the typical narrow, curved form associated with deposition of littoral drift, and four historical surveys (1854, 1873, 1917 and 1944) reveal varied but appreciable rates of westward growth averaging about 30 feet per year for the Spit tip. Further extension of Willoughby Spit has been prevented by coastal engineering works, including an extensive groin field dating to 1939 with a long terminal groin normal to the northern shore at the Spit tip.

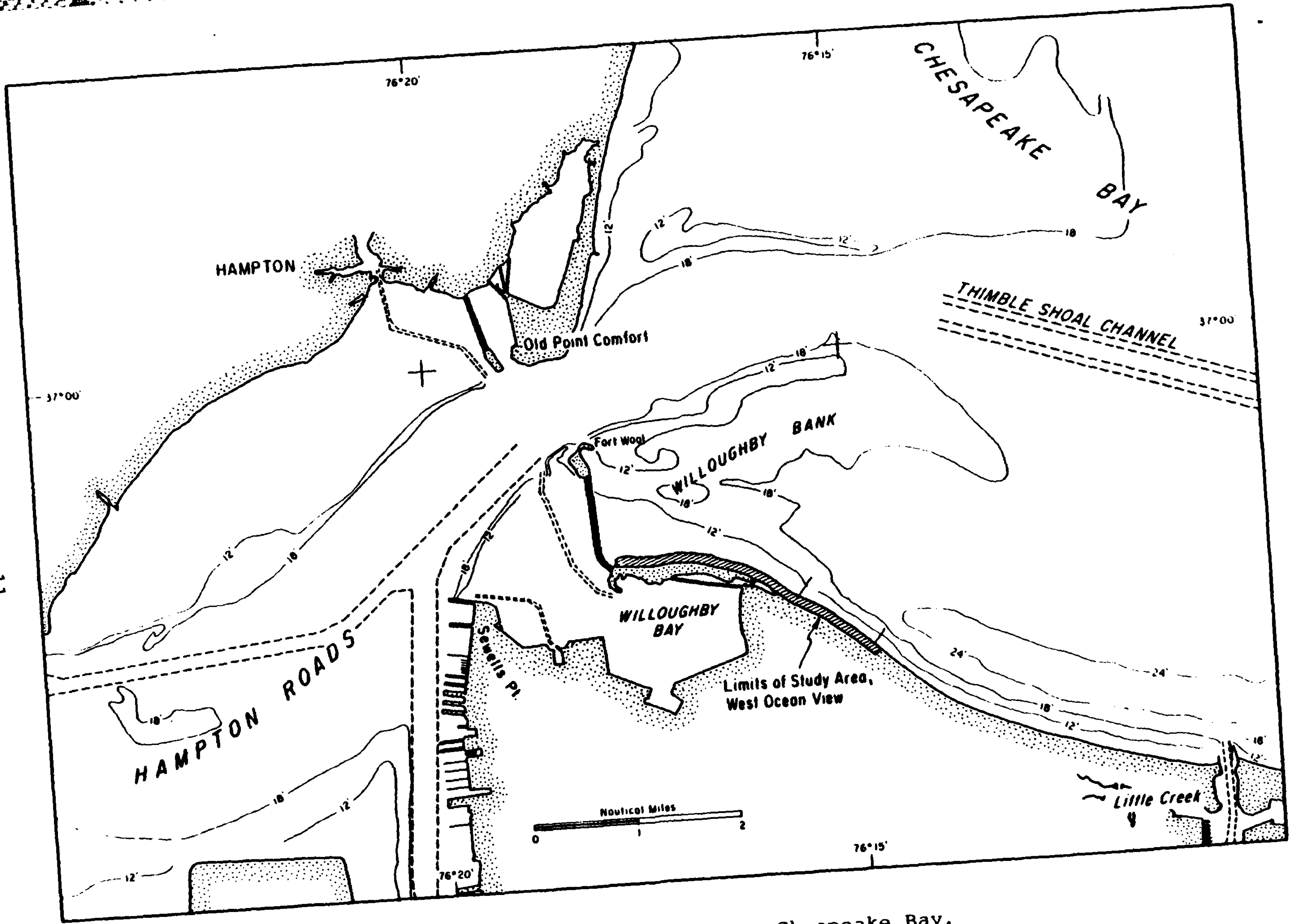


Figure 5. Setting of the study area in southwestern Cheapeake Bay.

Fleischer et al. (1977) measured current velocities offshore of 3 points along the Ocean View coast. Flood tidal effects were found to be dominant over ebb, with this dominance in duration and maximum current speed increasing westward. They also concluded that tidal currents 1200 yards north of Willoughby Spit are by themselves sufficient to transport sand, and that net westward sand transport rate due to offshore flood tides probably exceeded the net westward nearshore sand transport due to waves along Willoughby Spit.

At weekly intervals over one year, Fleischer et al. (1977) collected data on Ocean View coastal proceses at five sites. These data included: wind, wave characteristics, littoral current, suspended sediment, and beach profiles. The Ocean View environment was described as one of low to moderate wave energy, with smaller waves and lesser beach changes along Willoughby Spit than further east. Fleischer et al. (1977) believed that (p. 13) their observed winds were anomalous compared to long-term wind roses available to them. These available roses were collected at the Naval Air Station and at what was the Norfolk Municipal Airport. Compared to these wind roses, the wind observations of Fleisher et al (1977) over-represented winds from the northwest and north and under-represented winds from the northeast. However, Fleisher et al. (1977) probably have better, more representative wind data than they realized. In fact, their wind rose, collected at the shore of Willoughby Spit, resembles the wind rose of this report (see Figure 10) collected at the Bay-Bridge tunnel much more than it does the wind roses of the airports, about 1.5 miles inland. The inland wind roses are not representative of the bay winds because of the sheltering and refraction of the wind by land masses upwind from the airports.

Computations using the observed littoral-zone variables yielded predominantly eastward net sand transport. Because of the indications of westward transport at groins, these "should not be used as indicators of the net transport" (p. 27). The weekly profiles, however, should be quantitatively valid because beaches do not change as quickly as hydraulic conditions do; those data (Table 2 in Fleischer et al. 1977) show that average vertical beach changes at the eastern end of the present study area are nearly twice as large as on the western end of Willoughby Spit.

Ludwick (1979) emphasized the importance of tidal currents to the south coast of Chesapeake Bay. A shore-parallel trough about 1,000 yards north of the Ocean View coast is defined by 24-ft depth contours; this is stated to be a channel for flood-dominant tidal currents that accelerate to the west, with the south edge of the channel defining the lower limit to the local shoreface. Partial bathymetry from surveys in 1854 and 1978 is reported to show an onshore movement of the south channel wall at about 3 meters per year, eroding the shoreface at its base and resulting in beach erosion along Ocean View. On this coastal reach, longshore sand transport is judged to be more important outside the surf zone than inside, by both Ludwick (1979) and Fleischer et al. (1977).

Present Field Investigations. A major factor affecting the Ocean View study area is the extensive groin field in existence since 1939 (U.S. Army Corps of Engineers, Norfolk District, 1982). There are 37 groins about 275 feet long, oriented normal to the shoreline and approximately 500 feet apart. These groins are built of timber sheet piling overlapped in Wakefield style. In profile, the groins have three segments: a landward segment with horizontal crest at

+6 feet MLW for 100 feet, a seaward segment with horizontal crest at +2 feet MLW for 100 feet, and in between, an intermediate segment with a crest sloping from +6 to +2 feet MLW over 75 feet. This description is only approximate; individual groins vary. Also, it is not clear whether stated elevations correspond to 1939 MLW or 1982 MLW, about a 1/2-foot vertical difference. Since the shoreline at West Ocean View is curved, the azimuth (plan orientation) of these straight shore normal groins varies by about 55 degrees along Willoughby Spit (Figure 6).

Figure 6 locates the City groins along with profile lines surveyed during August 1983. Other investigations included sediment sampling on the 15 lines, drogue studies of ebb and flood currents in the study area, and measurements of the maximum difference in sediment level across each groin. Major findings are summarized as follows.

Beach and nearshore profiles are plotted on Figure 7 for each of the 15 lines identified on Figure 6. Separate surveys are overlaid in three groups with the MLW intercept as the common point. Beach profiles above MLW appear quite similar throughout the study area, but there is a marked and regular variation in profiles seaward of the beach. Proceeding east from the tip of Willoughby Spit, typical water depths about 2500 feet from the MLW shoreline increase smoothly from about 6 feet on line 1 to 25 feet on line 15. For the inshore profile segments, to about 300 feet seaward of MLW intercept, no dramatic alongshore trends are apparent but near Willoughby Spit the sand surface seems somewhat more concave, perhaps indicating a lessening supply of littoral drift. However, variation of inshore profiles could also be caused by three-dimensional beds differing between groin compartments.

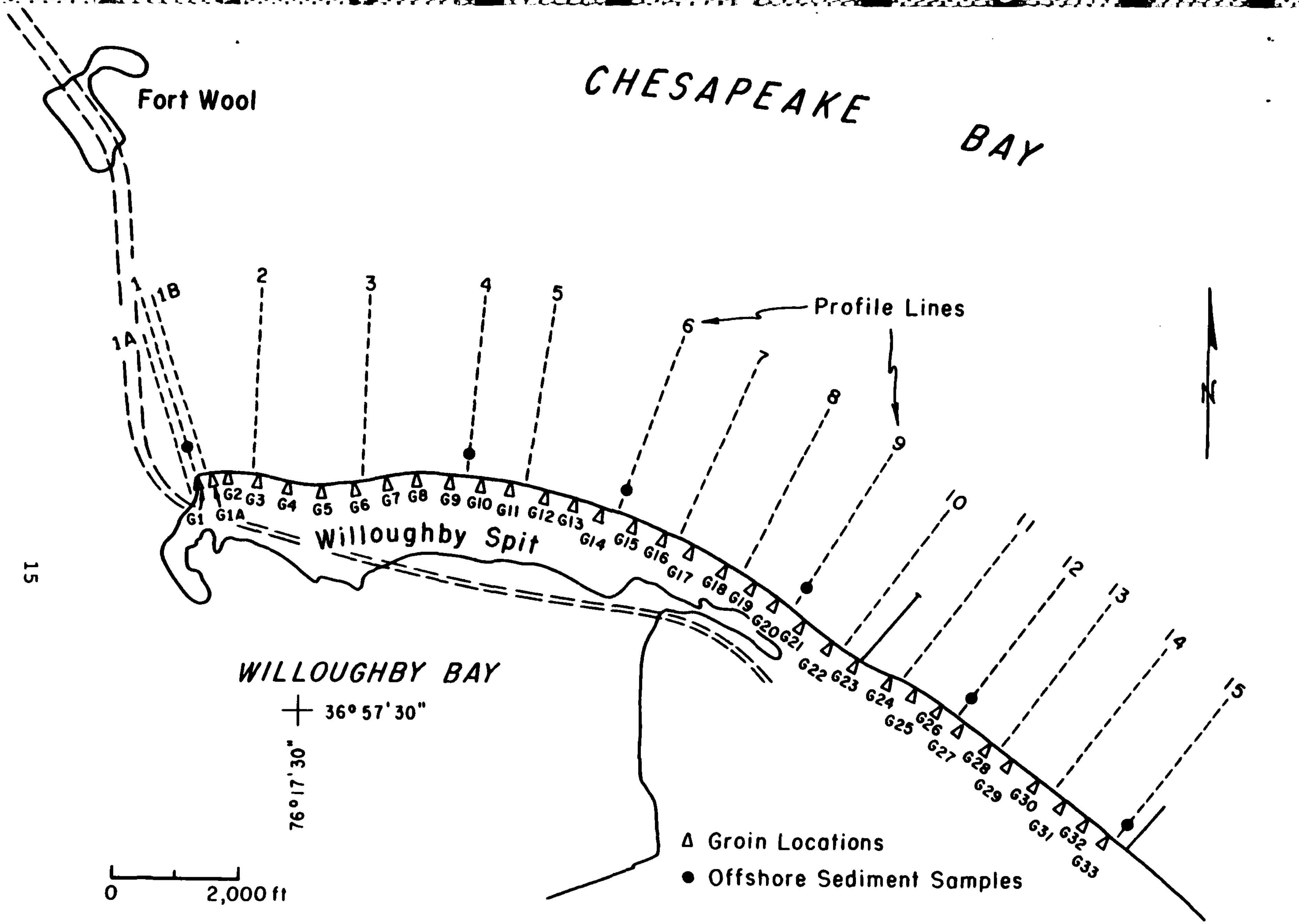


Figure 6. Locations of major shore structures and data collections within study area.

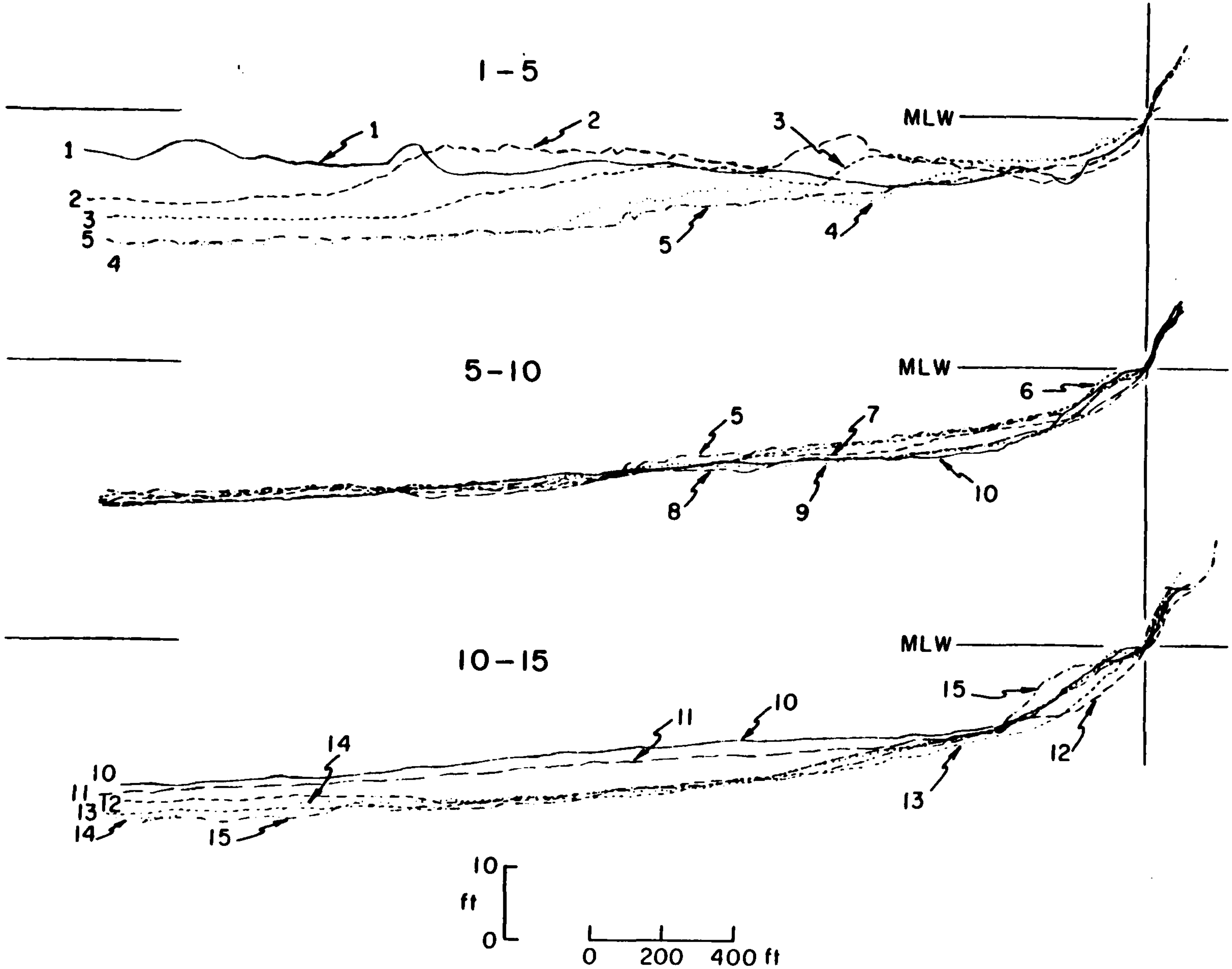


Figure 7. Beach and nearshore profiles in August 1983.

Two additional transects, 1A and 1B, were located 200 feet away from profile line 1, near the long terminal groin at the tip of Willoughby Spit. Figure 8 displays these survey results on a common baseline. The major point arising upon comparison is the appreciable nearshore sand deposit within about 750 feet of shore both west and east of the groin. The deeper shoreface profile measured on line 1 right at the east groin side perhaps is associated with the scouring action of currents attached to the groin.

Along the 15 profile lines, 44 sediment samples were collected: a foreshore sample on all lines; a berm sample on all except line 2; a dune sample where appropriate, i.e., on lines 3 through 9, 13, and 15; and an offshore sample on lines 1, 4, 6, 9, 12, and 15, each about 400 feet seaward of MLW intercept. Sieve analyses were done and Appendix B to this report provides graphs of alongshore variations in median and extreme sediment grain diameters (D_{50}, D_{16}, D_{84}), grouped according to the sample location. These samples from West Ocean View have great ranges of size and sorting, but fundamentally they are medium to coarse sand, with a representative grain diameter on foreshore or berm being about 1/2 millimeter. Major alongshore variations are found in offshore samples. Sand having median diameter near 1/3 millimeter occurs in the four samples seaward of Willoughby Spit, but two samples obtained further east contain primarily gravel. Occurrence of such coarse sediment in an environment of relatively low wave energy might be ascribed to the winnowing of finer fractions of original sediment (Fleischer, et al., 1977), or to the exposure and dispersal of coarse relict sediment (Ludwick, 1979). Grain-size distributions of 1983 samples of coarse sediments are manifestly not normal and appear to comprise two sediment subpopulations.

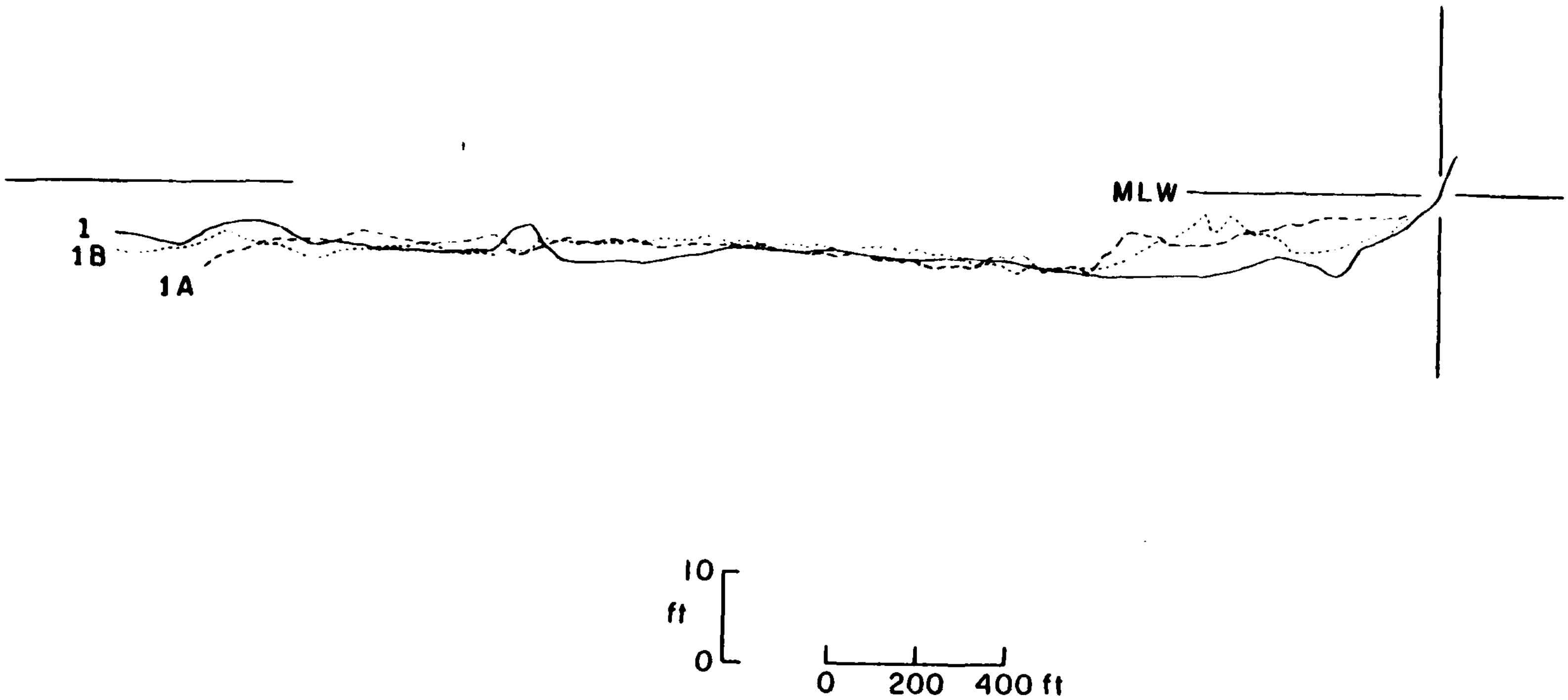


Figure 8. Profiles near and at 200-foot offsets from terminal groin on Willoughby Spit.

Tidal currents were measured by surface drogues at locations between profile lines 2 through 10 and from about 450 to 1600 feet offshore. As expected, both flood and ebb flows moved drogues nearly parallel to the local shoreline. The 34 observed speeds are compared in Table 2 with the expected currents based on Tidal Current Tables. Measured currents had nearly the same speed during peak flood or ebb flows, with representative values around 1.5 feet per second being nearly twice the speed needed to move local seabed sands (Fleischer et al., 1977). However, these ebb currents summarized in Table 2 were recorded during spring tide on 9 August 1983, whereas the flood currents were recorded during a less than average tide on 29 August 1983. Adjusting these results to typical tidal conditions by means of the "Tidal Current Tables 1983", representative values near Willoughby Spit are computed to be 1.7 feet per second for maximum flood current and 1.1 feet per second for maximum ebb current. Nearshore flood tidal flows thus seem much more important than ebb tidal flows in the study area, being capable of causing sand transport westwards which the ebb tide cannot significantly reverse.

The final class of 1983 field data are measurements of differences in bed elevation across each City groin. Maximum vertical difference of sand level was determined along with horizontal distance from that site to the waterline on the lower side. Such groin data measure amount and direction of net longshore transport, the updrift side being the side with sand buildup and the downdrift side the side with the sand deficit. Of 34 groins measured (1, 1A, and 2 through 33), 33 show a sand deficiency on the west side relative to the east side, indicating longshore transport is predominantly westward. The only exception is at groin

Table 2. Results from surface drogue studies of tidal currents near Willoughby Spit.

Observed Current Speeds*	Flood Tide, ft/sec	Ebb Tide, ft/sec
Mean	1.55	1.53
Median	1.50	1.55
Range	1.1 - 2.1	1.2 - 1.7
Expected Current Speeds**	1.50	1.90

* Due to times of drogue studies, observed speeds need adjustments to yield representative values; measured ebb currents were obtained at time of spring tides and are uncharacteristically high; see text.

** Maximum expected during times of drogue studies for 0.7 miles north of Willoughby Spit (36° 58.8'N, 76° 17.3'W); from pages 67 and 165 of "Tidal Current Tables 1983, Atlantic Coast of North America" (National Ocean Survey, 1982).

number 4 where the beach's berm is presently landward of the groin's onshore end, so that foreshore sand moving westward accumulates on the west side of this flanked groin where it is sheltered from wave action. Excluding groin number 4, the maximum differential in sand level is typically about 4.5 feet, with the location of this maximum about 15 feet from the downdrift waterline. Sand level on the east side of the groins is at the top for one-third of the structures. Note that there was a wide range in all measured values, due in part to differing condition of individual groins.

These 1983 measurements of sand impoundment at City groins may be compared with the related data of Fleischer et al. (1977), namely shoreline offsets across individual groins measured from 1957-1964 and 1974 aerial surveys. Figure 9 displays those horizontal offsets (waterline to waterline) along with the 1983 horizontal measure (waterline to site of maximum sand differential), which is usually a smaller value. The great majority of sand deficits are on west sides of groins, so that westward sand transport is strongly indicated by these data. Sand impoundment at individual groins appears quite variable according to Figure 9. The notable exceptions are at groin pairs numbered 8 and 9 and 24 and 25, which have large sand deficits on the west sides in each data set; these cases may be associated with changes in shore orientation.

Fleischer et al. (1977) interpreted east-side deficiences near the eastern end of the groin field as indicating "a net littoral transport stagnation or reversal". For the shore from Little Creek to Willoughby Spit, they concluded that net sand transport was "zero or slightly eastward" only along about 1400 yards at the east end of the present study area in Ocean View, due to the change in

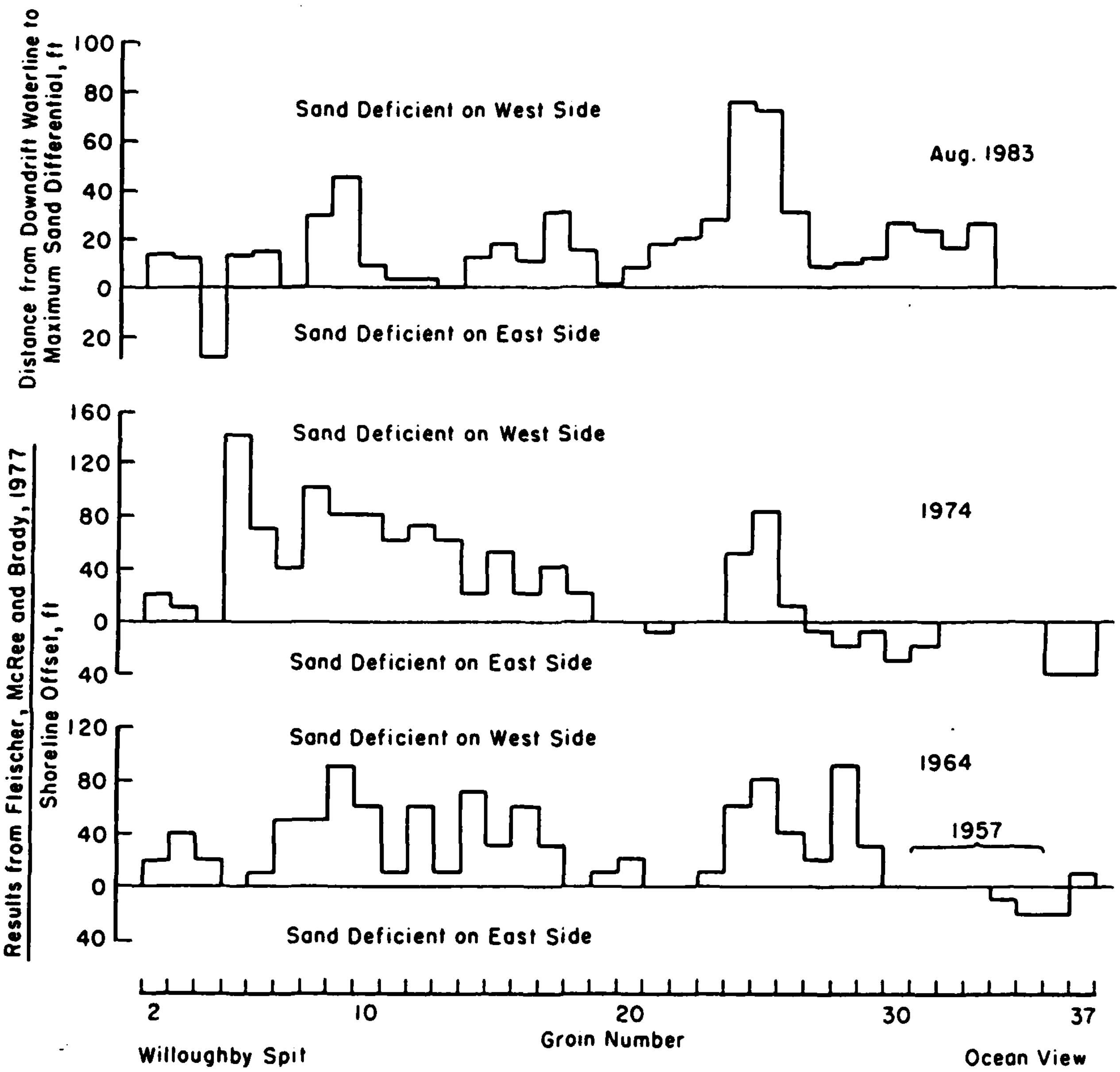


Figure 9. Shoreline displacements across individual Ocean View groins.

shoreline orientation there. However, it is also possible that this is a localized effect associated with timing of the 1974 aerial survey and that net longshore sand transport is to the west on this entire shore reach; the net westward rate of transport is expected to vary along the study shore, and eastward sand transport is expected to occur occasionally.

Evidence of eastward littoral transport was not recorded at any shore structure in the study area during 1983 field investigations, which included data collection in August and site inspections on 23 May and 13 December 1983. However, May 1983 aerial photographs contain possible evidence for varying direction of longshore sand transport: shorelines in all compartments between groins numbered 10 through 18 have bumpy forms apparently indicative of reversal in longshore transport, as distinguished from the smoothly curved fillet indicating unidirectional littoral transport. Those aerial photographs also show that absolute elevation of groin tops varies noticeably; for example, the seaward segments of groins numbered 11-15 remain submerged while those of 8-10 are exposed. Observations and sand samples from the two site inspections do not seem definitive concerning possible seasonal effects on beaches in the study area.

COASTAL PROCESSES OF STUDY AREA

Shore and nearshore processes near Willoughby Spit are essential considerations for the present feasibility assessment concerning beach disposal. The 1983 field investigations basically addressed present conditions rather than processes, and studies by Flesicher, et al. (1977) and Ludwick (1979) require elaboration for application to coastal engineering design. Material in this section develops an overview of important processes from accessible information and estimation procedures.

Local Environment. Extensive data is available on the marine environment of lower Chesapeake Bay between Hampton Roads Entrance and the Atlantic Ocean. Table 3 provides a summary of local sea measurements: water levels, currents, and wave characteristics. Local sea level rise has been rapid compared to other East Coast sites (Hicks et al. 1983). Tides are semidiurnal, with moderate ranges and appreciable current velocities. Wave heights can be moderately large for "extreme" conditions, defined as the worst wave conditions to be expected 12 hours per year.

Tidal characteristics exhibit notable diversity near Hampton Roads Entrance. Flood currents are dominant at the north side of the Entrance (Old Point Comfort) and ebb currents are dominant at the south side (Fort Wool). Near the southern shore of Chesapeake Bay, the only site with a listed dominance of flood over ebb tides is that directly north of Willoughby Spit.

Table 3. Summary of basic marine environmental measurements for southern Chesapeake Bay.

A. Sea Level Trend (Hicks et al., 1983)

Hampton Roads/Sewells Point: 36° 56.8'N, 76° 19.9'W
+4.3 mm/year (0.014 ft/year), 1928 through 1980
+3.6 mm/year (0.012 ft/year), 1940 through 1980

B. Wave Climate (based on data by Thompson, 1977)
Thimble Shoal Channel: 36° 58'N, 76° 07'W; April 71-Aug 74

	Measured Wave Conditions: Median	Average	Extreme
Height, ft:	1.35	1.62	7.6
Period, sec:	3.40	3.70	5.5

C. Tidal Characteristics (National Ocean Survey, 1982a/b)

	Tidal Ranges:			Time of Tide Relative to Hampton Roads	
Shore Sites	Mean Level ft MLW	Mean Range ft	Spring Range ft	High Water min	Low Water min
Hampton Roads (Sewells Point) 36°57'N, 76° 20'W	1.2	2.5	2.9	---	---
Old Point Comfort 37°00'N, 70°19'W	1.3	2.5	3.0	-04	-14
Little Creek (RR Terminal) 36°55'N, 76°11'W	1.3	2.6	3.1	-48	-50

Table 3 (continued)

Marine Sites	Tidal Currents: knots/direction/ relative time, hr:min					
	Maximum Flood			Maximum Ebb		
"Chesapeake Bay Entrance" 36°58.8N, 76°00.4'W	1.0	306°	---	1.5	126°	---
Deep-Water Entrance 1.8 miles N of Cape Henry Light 36°57.4'N, 76°00.1'W	1.2	292°	-0:11	1.5	099°	-0:17
1 mile N of Cape Henry Light 36°56.4'N, 76°00.5'N	1.1	280°	-0:25	2.0	090°	-0:25
0.5 mile N of west jetty, Little Creek 36°656.32'N, 76°10.81'W	0.9	274°	-1:03	0.9	108°	-1:31
0.7 mile N of Willoughby Spit 36°58.8N, 76°17.3'W	1.0	285°	-2:05	0.8	080°	-3:05
0.8 mile NW of Willoughby Spit 36°58.6N, 76°18.4'W	0.7	260°	-2:25	1.0	040°	-2:25
0.7 mile SW of Fort Wool 36°58.85'N, 76°18.85'W	0.6	250°	-2:39	1.3	045°	-2:17
0.2 mile NW of Fort Wool 36°59.3'N, 76°18.52'N	1.3	240°	-2:07	2.0	050°	-1:54
0.4 mile NE of Fort Wool 36°59.5'N, 76°17.8'W	1.0	258°	-1:46	1.4	066°	-1:52
0.9 mile NE of Fort Wool 36°59.8'N, 76°17.2'W	1.0	265°	-2:03	1.8	080°	-1:47
0.2 mile S of Old Point Comfort 36°59.77'N, 76°18.88'N	1.7	240°	-1:20	1.4	075°	-1:56

For the south shore of Chesapeake Bay, fairly representative waves should occur at the wave gage site mentioned in Table 3; that gage was located on South Thimble Island near the intersection of Thimble Shoal Channel with the Chesapeake Bay Bridge-Tunnel route. Figure 10 provides a wind rose for 1981 data obtained at the same site. The maximum wind speed in the year of data used to develop the wind rose was between 40 and 45 knots. The median was 11 knots. Extreme winds mostly had a component out of the north, so that the fetches up the middle of Chesapeake Bay should give typical lower Bay seas at the gage site (Appendix C). The question of what Atlantic Ocean waves are typical is more difficult: wave periods are relatively small in gage records, perhaps due to the sheltered site west of South Thimble Island. Overall, Bay waves rather than Ocean waves are expected to dominate coastal processes of the study area (see below).

Computations: Waves and Limit Depths. One major application for available wave measurements is in estimating seaward limits to appreciable sand movements. The seaward limits considered here are those defined in Hallermeier (1981): a maximum water depth for surf effects, d_s, based on an extreme wave condition, and a maximum water depth for usual sand motion, d_m, based on median wave condition and sand diameter. Taking D = 0.13 mm for the fine gray sand common in lower Chesapeake bay (Meisburger, 1972), Table 3 wave conditions from the Thimble Shoal Channel gage yield d_s = 13.3 feet and d_m = 17.8 feet. Both water depths are with respect to MLW, and fractional feet in the computed depths are to be rounded upwards to the nearest foot for engineering usage.

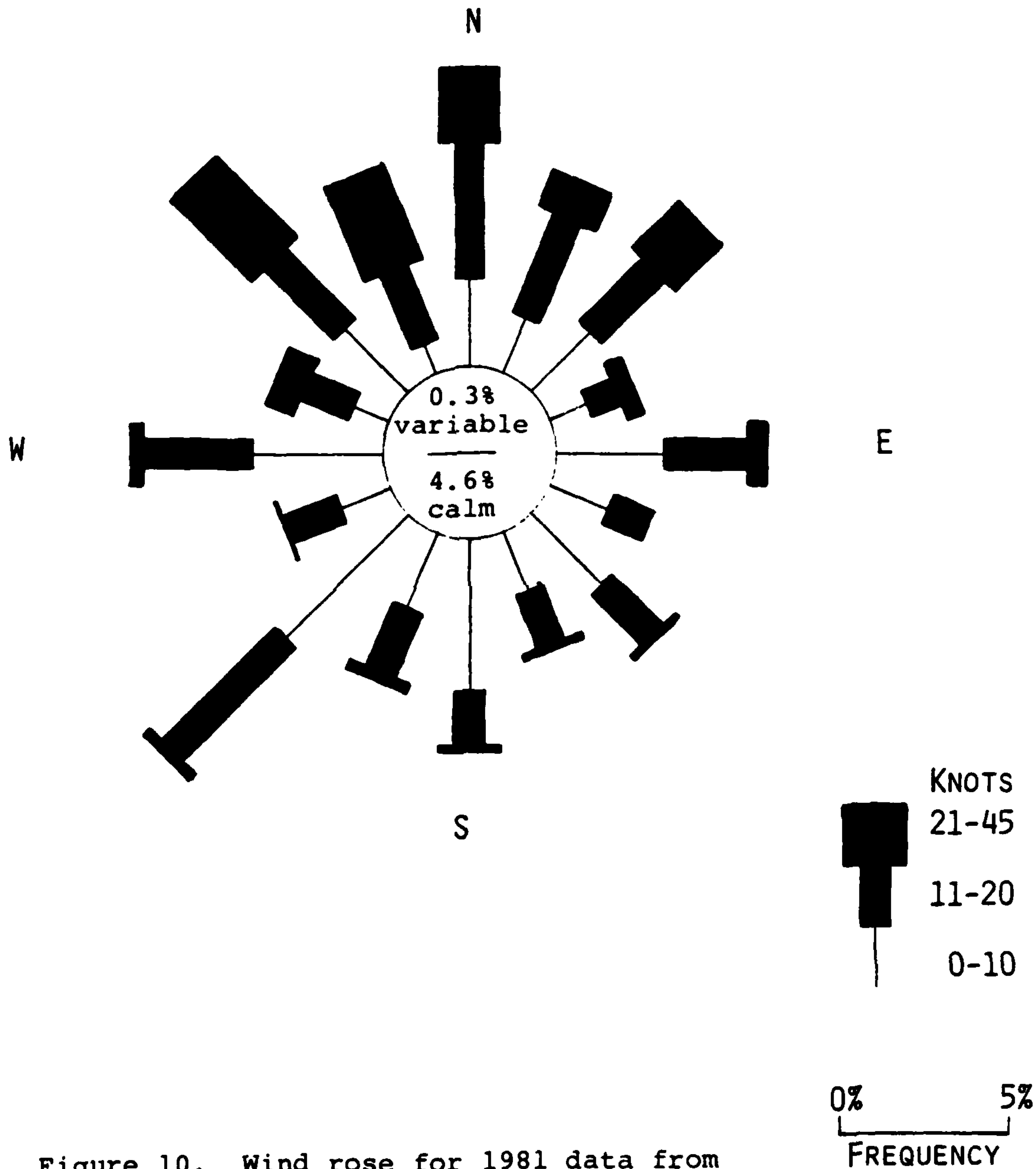


Figure 10. Wind rose for 1981 data from Chesapeake Bay Bridge-Tunnel (South Thimble Island)

The pertinence of these computed values must be examined for the study area some 8 nautical miles west of the wave gage site. Appendix C documents details of investigations quantifying Bay exposure of sites under consideration, with findings summarized as follows. For the wave gage site, effective fetch for Bay waves was estimated at 29.4 nautical miles, with the central fetch radial near compass direction 355° and representative water depth of 35 feet MLW within the fetch. Two sites along the West Ocean View study area were examined: near profile line 3, effective fetch is 22.5 nautical miles with central radial at about 020° and representative water depth of 34 feet MLW; further east near profile line 9 where Willoughby Spit seems to start, effective fetch is 26.0 nautical miles with central radial at about 015° and representative water depth of 35 feet MLW.

Table 4 presents forecast Chesapeake Bay waves for the three fetches stated above and five wind speeds. For the higher wind speeds and the longest fetch, computed wave heights and periods correspond well to measured storm conditions, i.e., to larger than ordinary waves at the Thimble Shoal Channel gage (compare Table 3B). For the median (11 knot) wind, wave height seems appropriate but computed period is usually less than that measured (Table 3B). This suggests a significant admixture of long-period Atlantic waves at the gage site. Table 4 also reveals that a 39 percent change of fetch results only in about 5 percent changes at most to forecast wave height or period for these shallow-water conditions.

Another factor in adapting the wave gage data to the study area is the alignment of central fetch radial with predominant wind directions. The gage site has exposure

Table 4. Forecasts of wave conditions for lower Chesapeake Bay with north winds. Significant wave heights and periods are for constant water depth of 35 feet.

Wind Speed knots		Fetch Length Nautical Miles 22.5	26.0	29.5
11	H, ft.	1.7	1.8	1.9
	T, sec.	2.8	2.9	2.9
25	H, ft.	4.2	4.3	4.4
	T, sec.	4.3	4.4	4.5
30	H, ft.	4.9	5.0	5.2
	T, sec.	4.7	4.8	4.9
35	H, ft.	5.7	5.8	5.9
	T, sec.	5.0	5.2	5.3
40	H, ft.	6.2	6.4	6.5
	T, sec.	5.3	5.4	5.5

directly into strongest winds, slightly west of north, whereas the sites in West Ocean View have central radials approximately 20° eastward of that. Standard procedures would account for this by reducing the effective fetch for the Ocean View sites through a multiplicative factor of cos (20°) = 0.94.

The limit depth d_m varies as height times period of usual waves. With d_m = 17.8 feet for the wave gage site, the preceding considerations indicate that appropriate estimates for d_m are about 15.7 feet and 14.3 feet near profile lines 9 and 3, respectively. Thus, d_m = 15 feet seems a representative estimate for the usual seaward limit to sand motion for the study area.

In adapting the d_s estimated for the wave gage site to conditions at the study area, an overwhelming factor appears to be frictional dissipation over nearby shoals of extreme waves before reaching the nearshore zone. Appreciable dissipation arises in wave propagation over agitated bed sands, but standard shallow water forecasting curves take into account only minimal friction. To assess this effect, extent of nearshore shoals above the 18-foot isobath ($\simeq d_m$) was measured for the two Ocean View shore sites considered above. About 8 nautical miles of shoal lie on the central radial for profile line 3, and about 6 nautical miles for profile line 9.

A moderate estimate for such frictional dissipation is that a 5 percent wave-height decrease results per nautical mile (see Hallermeier, 1983), so resultant wave height might be reduced to about $(0.95)^8 \simeq 2/3$ at line 3, and $(0.95)^6 \simeq 3/4$ at line 9, each fraction with respect to incident wave height. Based on these factors and results in Tables 3B and

4, appropriate adjusted values for d_s appear to be: 9.2 feet at profile line 3, from H = 4.8 feet and T = 5.3 sec; 10.2 feet at profile line 9, from H = 5.4 feet and T = 5.4 sec. Thus, d_s = 10 feet seems an adequately exact estimate for the seaward limit to extreme surf effects in the study area.

Other Computations. Simplified considerations can help clarify the cause and effect relationship between complicated tidal flows and bathymetry on Willoughby Bank north of the study area. Relative strength of tide-induced sand transports can be estimated taking into account peak flood and ebb currents with their directions and durations. With the approximations of a sinusoidal tide, sand transport rate depending on the cube of flow velocity, and a reasonable threshold flow for any transport of 0.5 knots (Fleischer, et al. 1977), potential amounts of sand transport due to reported tidal currents were estimated using

$$\left(\int (C \sin \Theta - U_o)^3 \, d\Theta \right) T_c \qquad (1)$$

Here C is peak flood/ebb current speed, U_o = 0.5 knots is threshold for sand motion, the integral is taken over the portion of flow phase when current speed exceeds U_o, and T_c is the time duration for the flood- or ebb-flow interval.

Figure 11 illustrates results computed for 12 sites near the study area, with a schematic indication of relative sand transport capacities over each tidal stage. Most appreciable tidal transports in this area flank Hampton Roads entrance and may be expected to be a dominant factor shaping the sand bed there, including the northern edge of Willoughby Bank. Although 1983 drogue studies indicated that

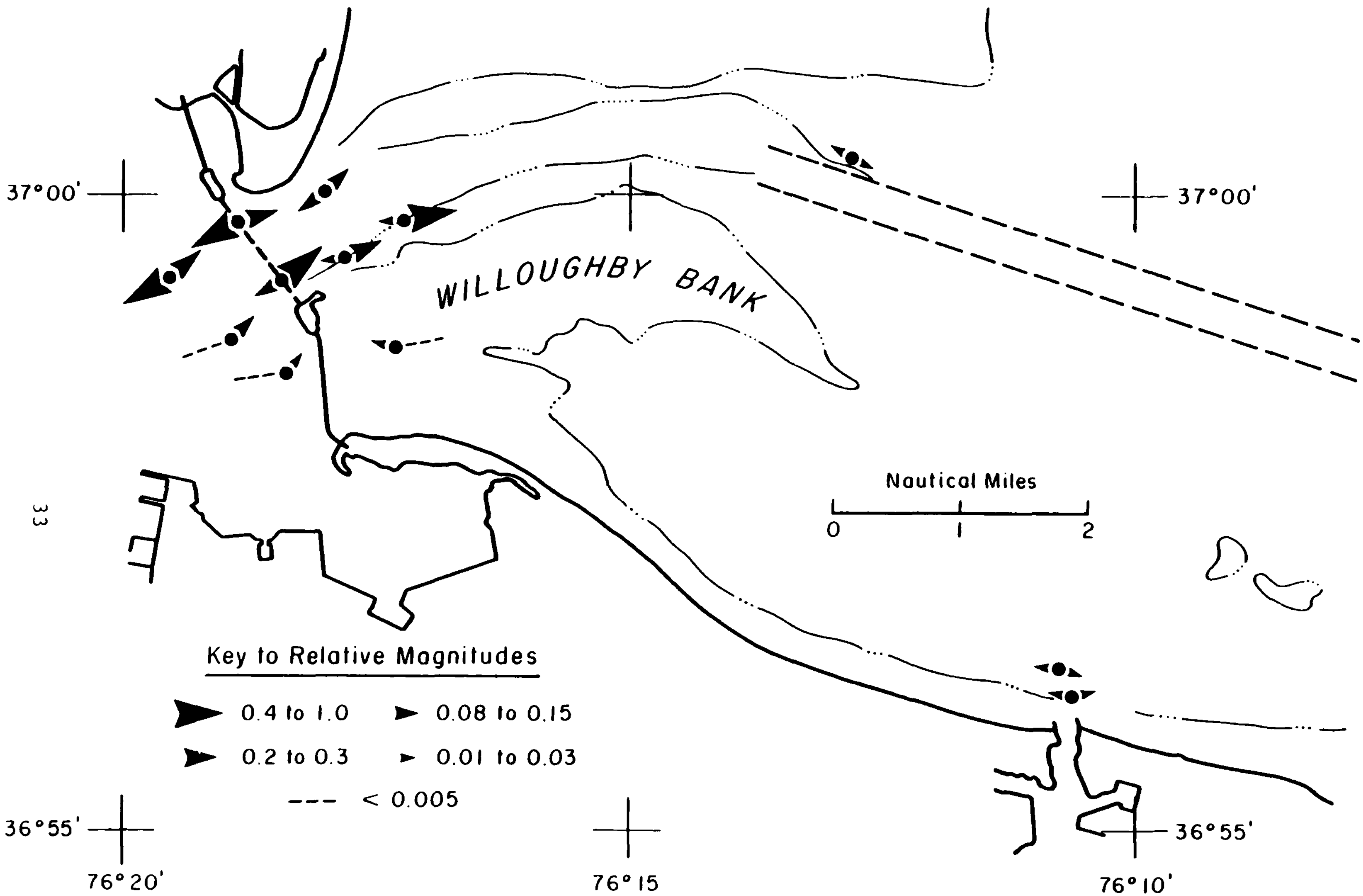


Figure 11. Computed sand transport capacities of tidal currents near study area.

flood tidal currents dominate ebb just offshore of Willoughby Spit, representative speed there would rate only the smallest arrowhead used in Figure 11. Thus, compared to the surrounding area, relative importance of tidal sand transports near the Ocean View shore seems minor, even for the station near the flood-tidal channel or sinus (Flesicher et al. 1977) apparently cutting WNW across Willoughby Bank.

Overview of Dominant Processes. For the study area in southwestern Chesapeake Bay, tidal currents are clearly significant in that the ebb current predominance at southern Hampton Roads Entrance is capable of shaping the relatively steep northern flank of Willoughby Bank. Expansion of ebb flow away from the Entrance constriction along with rightward Coriolis inclination would account for the elongated eastern Bank lobe clearly indicated by the 18-foot isobath. The southern face of the lobe exhibits no evidence of flow-contouring action, and Ludwick (1979) reported that the entire lobe "has not shown a major change in the past 124 years." Deeper water directly south, near 76° 14' W, 36° 59' N, should be associated with a relatively inactive bed, sheltered from wave action.

A typical depth on eastern Willoughby Bank is 15 or 16 feet MLW, supporting the value of d_m = 15 feet MLW developed above for the western Ocean View region: common Bay sands atop the Bank would not be stirred by usual Bay waves, resulting in a durable deposit. This also implies some support for the estimated d_s = 10 feet MLW, and that value seems approximately confirmed by the apparent discontinuities in Figure 7 between flat offshore shoal and curved (surf-dominated) nearshore profile segments on western Willoughby Spit (Figure 6). These results tend to substantiate the preceding analyses for Bay waves as the major

energy source expected along West Ocean View, but two other wave sources appear to influence littoral sand transport in this study area.

At the tip of Willoughby Spit, the fetch westward is sufficiently long that winds exceeding 15 to 20 knots can generate waves competent to erode the shoal (above -6 feet MLW) directly W to NW of the Spit. Given the large sand supply available there, occasional events with eastward littoral transport due to such Hampton Roads waves can be a significant factor on the north-facing Willoughby Spit shore.

For the eastern half of the study area, shore orientations and the direction of major Bay fetches indicate that Atlantic Ocean waves are important to the net westward littoral sand transport. Table 5 summarizes the orientations of City groins. Allowance for typical offsets at groins yields directions of local shore normals which are perhaps 5 degrees further east. Such values are to be compared to the compass heading of about 015^{o} for a central radial of Bay fetch representing the eastern study area. East of groin number 12 or profile line 5, typical Bay waves approach Ocean View with an oceanward component and direct longshore transport eastward. This might be slightly counteracted by expected gradients in Bay-wave energy, which must lessen going westward along this shore, but waves from the Atlantic Ocean appear to be the ones which tip the net longshore transport balance westward (according to most shoreline indications). Over approximately 15 nautical miles from the Chesapeake Bay Entrance to the study area,

Table 5. Approximate compass orientations of City groins along West Ocean View, Norfolk, Virginia.

Groin Numbers	Orientation, degrees
1	347
1A to 10	003
11, 12	013
13 to 18	024
19 and up	042

Ocean waves will be reduced to half initial height $[(0.95)^{15} = 0.46]$ but long, low waves quite oblique to shore can be effective in transporting beach sand westward towards Willoughby Spit.

Flood currents flow westward along shore with significant speed, but the quantitative importance of the inferred tidal sand transport in moderate water depths remains to be assessed. For a beach disposal project, shoreline processes are critical and tidal currents might be prevented from directly affecting the shore by the City groin field. Presuming tidal currents to be significant and the groins to be an effective hydraulic barrier, there should be a resultant distinct change of profile form in the vicinity of the groin ends, e.g., a deepening seaward of the groins. Whether this is so requires locating the groins and the profiles on the same map.

Given the history and setting of Willoughby Spit, oblique waves and longshore sand transport are expected to dominate natural coastal processes, but such processes have been regulated by installation of the groin field. According to accepted practice (Tomlinson, 1980; Shore Protection Manual, 1977), the Ocean View groins are longer, more widely spaced, and lower than would now be customary. These groins clearly have a strong influence on shore processes, as indicated by sand differentials from updrift to downdrift side (Figure 9). Although sand is impounded, no downdrift shore appears significantly deprived of littoral drift, except perhaps near the Spit tip. The configuration of these sizable and effective shore structures is a crucial consideration in designing a disposal operation having maximum effectiveness.

BEACH DISPOSAL AT WEST OCEAN VIEW

The eastern limit to eroded beaches within the study area is estimated to be between profile lines 11 and 12 (Figure 6). The shore between lines 11 and 12 includes groins 25 and 26. We recommend that all groin compartments west of groin number 26 be filled. The major reason for this choice is the fact that east of groin 26 the offset at groins has varied in direction (Figure 9), but west of groin 26, the offset has consistently indicated a sand deficiency on the west side of groins. West of groin 26 to the end of Willoughby Spit, shoreline offsets at groins suggest a deficit in beach sand. Groin number 26 marks the location where Ocean View shoreline starts to recurve: generally, there is concavity towards Chesapeake Bay east of groin 26, but convexity west of there along Willoughby Spit. This convexity to the west is interpreted as indicating a deficit in beach sand along Willoughby Spit.

Sand Characteristics. Figure 12 displays two alternatives for a native composite sand-size distribution. WOVA was computed by giving equal weight to each of 25 samples, including foreshore, berm, and offshore, from profile lines 1 through 11 (Groins 1 through 24; see Figure 6). WOVB was formed in a way designed to give more weight to the offshore samples which are available only from lines 1, 4, 6, and 9. On these 11 profile lines, the 4 offshore samples are given a weight of 0.5 and 8 berm and foreshore samples from the same lines providing the remaining weight of 0.5. There is very little difference between these two composite grain-

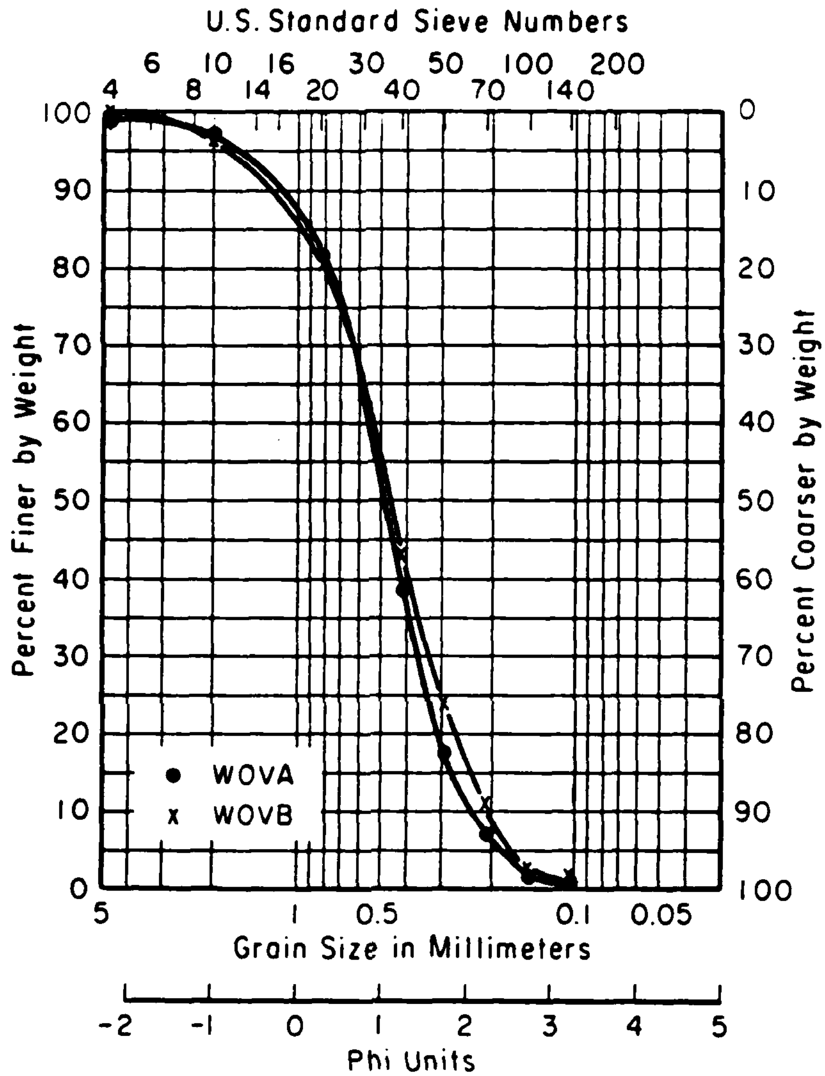


Figure 12. Two composite grain-size distributions for West Ocean View beach disposal sites.

size distributions, WOVA and WOVB (Figure 12). Seasonal variations in nearshore sediment characteristics may also be expected to be slight at West Ocean View. For design purposes, WOVB is used here.

Native sand is relatively well-sorted and coarse, with D_{50} about 1/2 millimeter, whereas the available channel sands (Figure 4) are noticeably finer, with D_{50} nearer to 1/4 millimeter. Table 6 summarizes computations relating to the compatability of each channel sand if disposed at the eroded study area. Mean M and sorting S are obtained using D_{16} and D_{84} values determined from linear interpolation in the cumulative size distribution on phi-probability graph paper. M and S then determine numerical factors R measuring compatibility of dredged and native material, according to published methods and design curves (Hobson, 1977; "Shore Protection Manual"). Results in Table 6 show that Dredging Area Y is much more suitable than Dredging Area Z as a source of beach sand for West Ocean View and that sediment from Area Y matches moderately well with WOVB sediments.

The two fill factors, R_A and R_D, provide estimates of the fill material volume needed to create a unit volume of native beach material according to procedures that have been used in practice. With sediment from Area Y, the indicated volumetric overfills (50%, 30%) are neither large nor small, but R_A and R_D are undesirably large with sediment from Area Z. The renourishment or durability factor, R_J, indicates the estimated ratio of beach retreat rate with dredged sediment, to that with native sediment; using values of R_J, sediment from Area Z is only about one-third as durable as native beach material, but sediment from Area Y will be about three fourths as durable as sands exactly matching the native beach material. These considerations show that the

Table 6. Basic results in beach-disposal computations, for two possible dredging sites in eastern Thimble Shoal Main Channel with sediment to be applied to the 4200 yards of Willoughby Spit shoreline west of City groin number 26.

A. Descriptions of Sediments

(phi units)

Parameter	Native Beach WOVB	Channel Material Composites: Area Y	Channel Material Composites: Area Z
D_{16}	0.09	0.36	1.09
D_{50}	1.07	1.85	2.10
D_{84}	2.06	2.68	3.01
$M=(D_{84}+D_{16})/2$	1.075	1.52	2.05
$S=(D_{84}-D_{16})/2$	0.985	1.16	0.96

B. Compatibility Measures of Potential Dredged Materials with WOVB

	Adjusted SPM Fill Factor, R_A	Durability Factor, R_J	Dean Fill Factor, R_D
Sediment Y	1.5	1.3	1.3
Sediment Z	5.0	2.8	2.7

channel material designated as Y on Figure 3 could be appropriately disposed on eroded West Ocean View beaches, though it is not ideally suited as beach fill there.

Marine Stockpile. Dredging Area Y is about 10 miles from the Willoughby beaches. An offshore, submarine stockpile in southwestern Chesapeake Bay may be used advantageously before placing sand on the beach. Stockpiling would be beneficial because double handling of channel material will reduce the fraction of the fines in the sand-size distribution, thus yielding a coarser remnant better suited as fill for West Ocean View. A suitable site for the marine stockpile must be reasonably close to Willoughby Spit; be relatively inactive under expected sea conditions so that the stored resource remains recoverable; and offer adequate storage capacity for the expected 850,000 cubic yards without posing a navigation nuisance.

An appropriate site appears to be south of the smooth arc in the 18-foot depth contour, directly south of eastern lobe to Willoughby Bank. A rectangular area 800 yards east-to-west by 600 yards north-to-south can be designated near $76^{o}14.5'$W, $36^{o}58.7'$N; this is about 2 miles ENE from the center of the eroded beaches at West Ocean View. Charted water depths are typically 21 feet MLW, so a deposit two yards deep can amount to 960,000 cubic yards with top elevation at -15 feet MLW not being prominently above Willoughby Bank and its shelter from Bay waves. The area is free of charted bottom hazards and appears to be neither a designated navigation route, nor anchorage area, nor in the path of strong tidal currents. Water depths of about 19 feet MLW would occur for at least a 300-yard wide band around the

proposed stockpile so that most dredged sand should remain discernible and recoverable even with some dispersal after long times. (Environmental or commercial effects are beyond the scope of this consideration.)

Figure 13 displays locations of dredging, stockpile, and beach disposal areas, to summarize distances and directions to be considered in arranging transportation.

Basic Design Considerations for Beach Disposal. The preliminary disposal design presented in this section is intended to work in conjunction with the existing groin field to provide a widened beach, where possible. The existing placement of groins and the present nearshore morphology are the major considerations in the development of the disposal design, aside from the suitability of the dredged material. Disposing of very large volumes of dredged material would bury portions of the groins and thereby decrease their effectiveness in providing wave shelter and slowing the rate of longshore sand transport; any excess material beyond the capacity of the groins would probably be removed from the disposal area relatively rapidly. Therefore, the objective of the recommended design is to fill groin compartments to their equilibrium capacity. Short-term redistribution and sorting of the dredged material following placement is expected. For this reason, a "full" groin compartment is considered, for the purpose of this design, to exist when the redistributed material has advanced the current equilibrium profile to the point where the crest of the berm contacts the top of the groin on the updrift face, as shown in Figure 14.

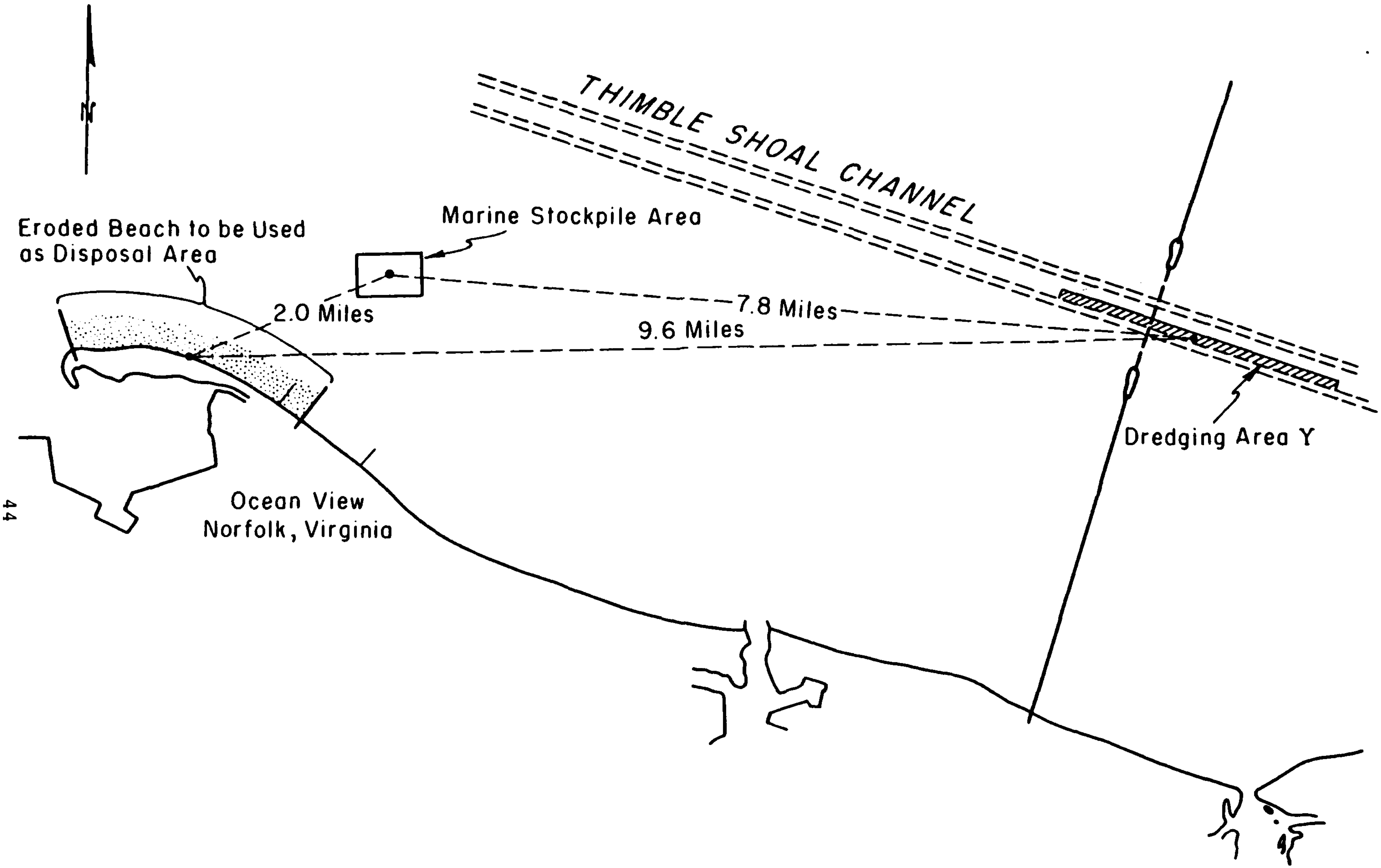


Figure 13. RELATIONS BETWEEN DREDGING, STOCKPILE AND DISPOSAL AREAS

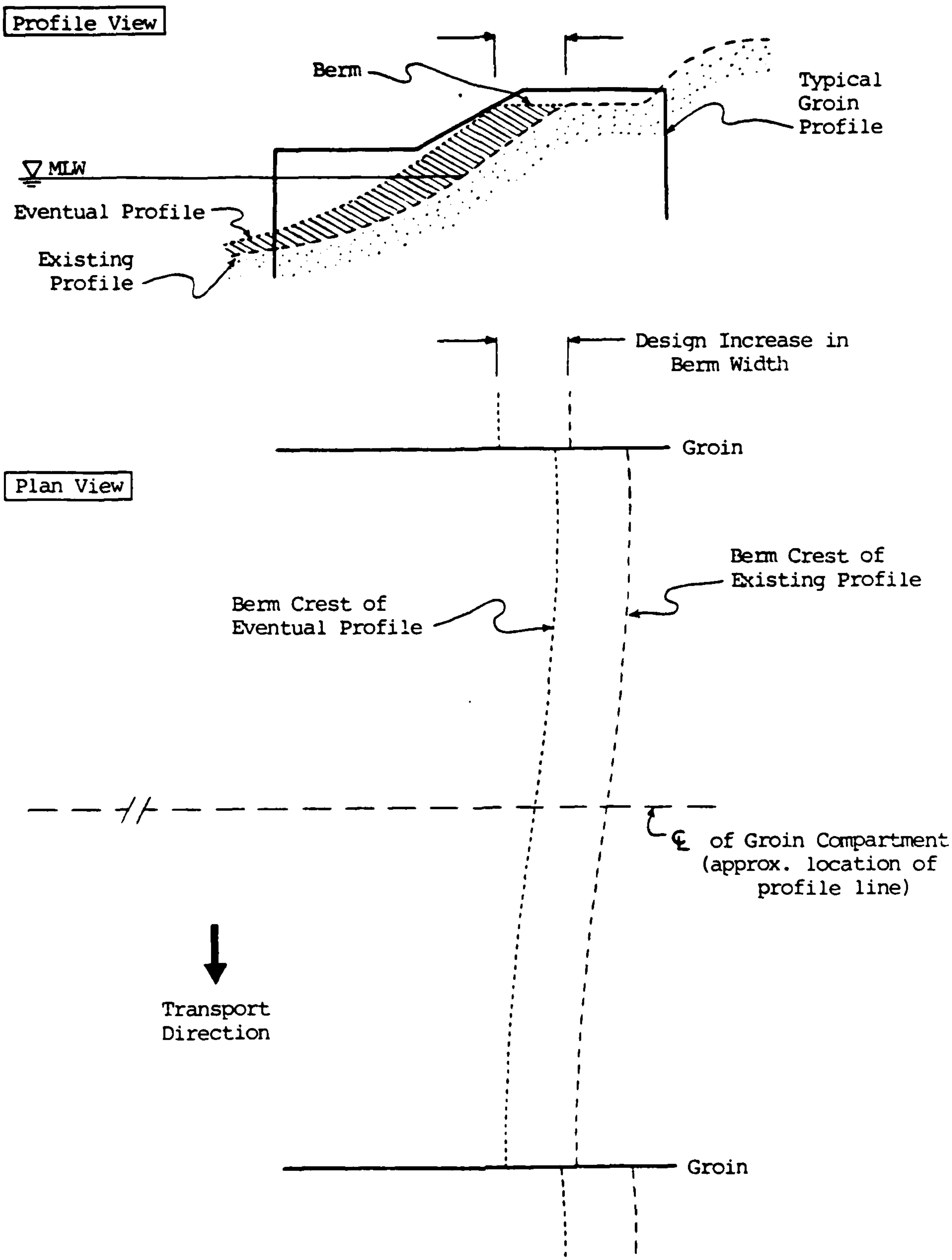


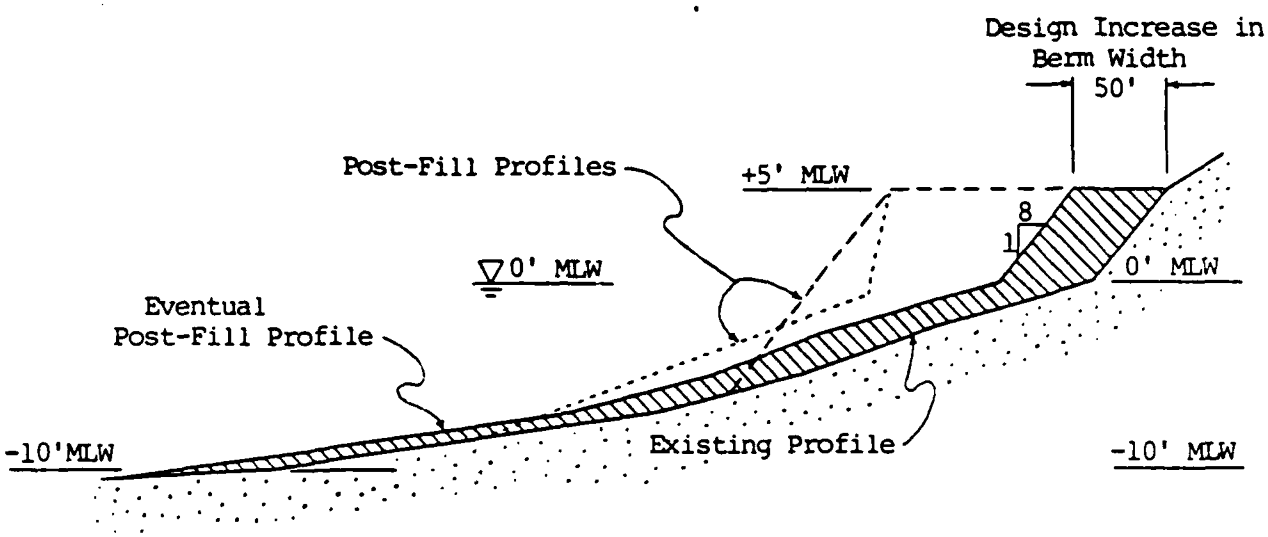
Figure 14. Elementary Geometry of Shore Profiles Relative to Groins for Basic Disposal Design.

Evidence from the field inspections and recent aerial photographs indicates that the compartments extending westward from Groin Number 26 to the terminal groin at the end of Willoughby Spit have varying amounts of remaining capacity. The angular orientation of groins to one another and to the shoreline, in combination with the general shoreline curvature, results in a staggering of groins in some stretches which reduces the capacity of some compartments. Due to a significant difference in angular orientation and profiles between Groins 1 through 10 and Groins 11 through 26, the fill reach was divided into those separate stretches for the analysis of typical profiles.

Characteristics of the dredged material affect the design primarily with respect to required volume of fill. Quantitative measures of performance of the dredged material as a replacement for native sand are the overfill factors and durability factor provided previously in Table 6. The basic fill volume requirement is computed employing the concept of equilibrium profile advance, with the overfill factor of $R_A = 1.5$ then applied as a multiplier. A final design might be based on the capacity for storage within the groin field to be determined by a more intensive nearshore survey than was available for this report. Of particular importance are measurements which correlate groin geometry with profiles, and which capture the three-dimensional variability in the shape of sand beds relative to groin compartments, by use of a common datum for elevations and baseline for positions. Also, design and performance of previous fills in the area should be examined.

Preliminary Design for Beach Disposal. The geometry of the preliminary disposal design is described by a berm elevation, an average seaward profile advance, and a typical

Typical Design Section East of Groin 10



Typical Design Section West of Groin 10

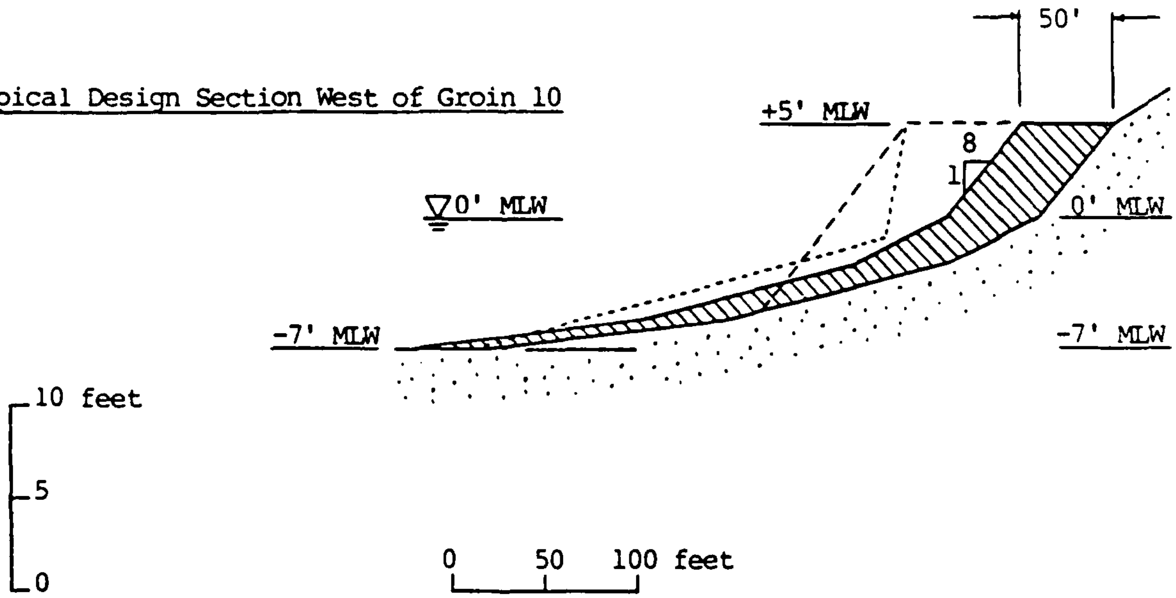


Figure 15. Preliminary Design for Beach Disposal Sections Along West Ocean View, Norfolk, Virginia.

profile shape from the berm to the maximum water depth for surf effects. Figure 14 illustrates the rationale for selecting an intended profile advance, and indicates the usual location of surveyed profiles in relation to groins. The groin geometry shown is that described in an earlier section of this report. Figure 15 considers the typical disposal geometry at mid-compartment.

The selection of +5 feet MLW as the design berm elevation was based on scrutiny of surveyed profiles, displayed in Figure 7, for evidence of a natural berm crest. Some variation in berm elevation within groin compartments is expected, with generally higher berms on updrift sides of groins. Since the surveyed profiles are located roughly at mid-compartment, they are assumed to be representative of the average profile shape and elevations.

On surveyed profiles there is little evidence of substantial horizontal berms in the disposal reach, thus Figure 15 shows a typical backshore slope landward of the berm crest. Rather than specify a berm width for design, an average profile advance of 50 feet was estimated to be appropriate (using the full compartments as a criterion) from a review of field data and photographs. Since the fill volume is relatively sensitive to this value, more precise estimates of the advisable profile advance for individual compartments are recommended prior to a final design.

Typical profiles for the east and west disposal sections shown on Figure 15 were drawn from overlays of surveyed profiles for the appropriate stretches of shoreline. Profiles 1, 1A, 1B, and 2 were eliminated from the averaging

due to their close proximity to groins, and are not considered to be typical of mid-compartment geometry. As discussed previously, the maximum water depth for surf effects on profile shape is estimated to be 10 feet MLW for the study area; the typical profile for the eastern disposal was considered to adjust out to that depth. However, surveyed profiles in the western disposal reach begin to curve upwards about 500 feet offshore, and it is apparent that extending the typical profile until it reaches the 10-foot depth would be unrealistic. Thus, the western disposal profile was ended at -7 feet MLW, which is where the surveyed profiles begin to level off. The shape of profiles seaward of that point is no longer primarily due to surf effects. (Note that the profiles on Figure 14 are shown as being steeper than those on Figure 15, due to their location immediately updrift of a groin.) A wetted foreshore slope of 1 on 8 is taken as representative of both disposal reaches. The existing slope was not adjusted to account for the difference between native and dredged material because large slope variations are expected within a single groin compartment, but those effects have not been quanitified.

The volume of dredged material required to achieve the desired shore advance, computed from the cross-hatched area shown on Figure 15, times the length of shoreline to be filled, times the overfill factor, is approximately 500,000 cubic yards, so there is sufficient material available in Dredging Area Y. The next practical consideration concerns the initial width of berm immediately following placement. Since it is impossible to control the grade of the fill on the exposed seaward face, the berm is ordinarily built seaward at the design elevation until the required volume has been placed. The dashed lines on Figure 15 show the

approximate shapes of dredged material and are representative of the required volume stated above. The foreshore slope is shown at a constant 1 on 8, but more likely would consist of a steep scarp above MLW, and flatter than 1 on 8 slopes below MLW. The build-out distance on Figure 15 is approximatey 150 feet for the eastern disposal section and 110 feet for the western section (at mid-compartment). Thus, the initial disposal berm, assuming a smooth shoreline across groins just after placement, will probably vary between 40 and 80 feet beyond the Figure 14 contact point for a "full" groin, and will bury a portion of each groin until some sand redistribution offshore has occurred.

An independent viewpoint of beach fill design is provided using the renourishment or durability factor (James, 1975), which is particularly appropriate on a coast known to be eroding. Durability considerations proceed from the assumption that rapid initial adjustment of placed beach material occurs without appreciable losses; the suitability of placed material then governs the rate of steady beach retreat to be expected. Using 50 feet as the design profile advance as above, the durability factor of $R_J = 1.3$ from Table 6, and a present shoreline retreat rate of 1.0 foot per year (1982 Norfolk District report on Willoughby Spit), 38 years is estimated to be the approximate time required for the dredged material to erode back to the present state. For the same geometries of adjusted profiles as are shown in Figure 15, the build-out distances are 110 feet for the eastern section to be filled and 80 feet for the western section; the required borrow volume totals about 340,000 cubic yards from this viewpoint. (These estimates do not consider an overfill factor or varying groin effects on shore retreat rates.)

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Sand from Dredging Area Y in Thimble Shoal Main Channel is fairly suitable for disposal at the eroded shore along West Ocean View. This conclusion is based primarily on new field data, including cores from the navigation channel, sand samples from the disposal area, beach and nearshore profiles, and tidal current measurements. The entire set of cores includes 42 cores taken at Thimble Shoal Channel, of which 28 are within the Main Channel and 3 of the 28 within Dredging Area Y (Figure 2). There are sieve analyses of 44 beach and nearshore sediment samples from the disposal area (Appendix B), surveys of 17 profile lines along West Ocean View (Figures 6 to 8), and 34 drogue measurements of nearshore tidal currents (Table 2). Differentials in sand elevations across 34 City groins (Figure 9) were also measured. Further pertinent information derived from other sources includes wind and sea data (Figure 10, Table 3), recorded coastal features (Figures 1, 5, 9; Table 5), and estimated waves, limit depths, and sand transports (Table 4, Appendix C, Figure 11).

The continuity of satisfactory sediment throughout Area Y has not been proven, and it must be demonstrated before proceeding, because Area Y includes only 3 of the 42 cores and is an unusally narrow 3-mile long area on the south side of the channel. Sediment from the three cores in Area Y typically consists of sand approximately 1/3 millimeter in diameter. Approximately 850,000 cubic yards of medium sand is available above -55 feet MLW in Dredging Area Y, if the 3 available cores represent a continuous sand deposit (Table 1, Figure 3). Dredging to -55.7 feet MLW will expose clay at the eastern core site, so that over-dredging should be limited.

Dredging Area Z is that designated in an earlier report as suitable for Fort Story beaches. Compared to sediment from Area Y, sediment from Area Z has more sand, but is finer. Based on existing fill criteria, sediment from Area Z is not as suitable for the Ocean View disposal area as is sediment from Area Y.

The disposal area is the western part of Ocean View, primarily Willoughby Spit and adjacent shores to the east. Erosion occurs on these beaches over the 4200 yards between groins numbered 1 and 26, about the western three-quarters of the study area including all of Willoughby Spit. Native sand along this reach is relatively coarse, with typical grain diameters about 1/2 millimeter, according to two alternatives for a composite sand size distribution (Figure 12). Quantitative procedures for estimating dredged material suitability show (Table 6) that Sediment Y should be appropriate to dispose on West Ocean View beaches, although not truly a close match to native material. The designated Dredging Area Y is approximately 10 miles due east of the designated disposal area. A submarine stockpile for sediment from Area Y could be sited about two miles ENE of Willoughby Spit (Figure 13). Figure 16 collects elevation values important to this project.

The eroded beaches need a restricted amount of sand for most efficient use of the existing groins. If disposal on these beaches advances the shore more than perhaps 100 feet, most of the seaward material would be quite exposed to the action of waves and tides, so that initial sand losses are expected to be relatively rapid until the foreshore retreats to within the seaward extent of the groins. Since these groins are effective barriers to longshore transport, we recommend placing only that volume of sand that will leave

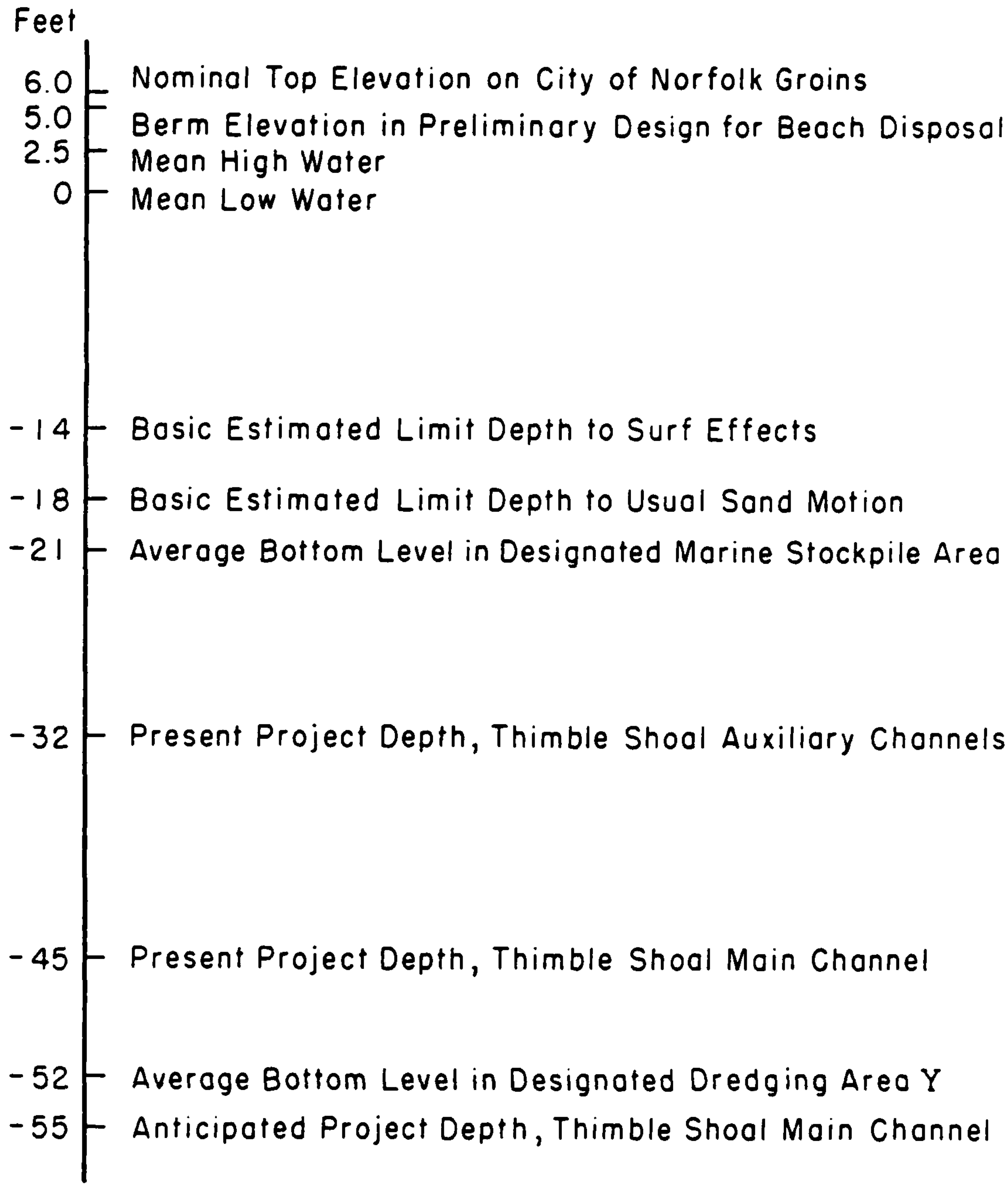


Figure 16. IMPORTANT ELEVATIONS FOR DISPOSAL AT WEST OCEAN VIEW, NORFOLK, VIRGINIA

groins as operational littoral barriers, i.e., the aim should be to make up local sand deficits within groin compartments and give a "full" groin field.

Another major consideration for beach disposal is the quality of match between dredged and native sediments. This is treated in the present report by examining both overfill and durability approaches, with the latter judged to be better for the actual situation on West Ocean View. At most, 500,000 cubic yards of the sediment from Area Y is needed to fill the eroded 4200 yards of shoreline in the study area.

The 3 cores in Dredging Area Y should be supplemented with additional cores to prove the continuity and extent of the usable sand. More exact information on the groins and the local bathymetry in groin compartments is needed. Top elevations of landward groin segments are needed to determine backshore elevation of the design section. Also, bathymetry and topography within groin compartments must be known in order to determine what reserve storage capacity exists, and what dredged material volume will be most suitable. Well-planned measurements of tidal currents near the Ocean View shore would be helpful in assessing the importance of longshore transport by tidal flows. An analysis of handling losses is needed to estimate how much stockpiling will improve the suitability of the sediment from Area Y sand for Willoughby Spit beaches.

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APPENDIX A

POTENTIAL BEACH DISPOSAL MATERIALS IN THIMBLE SHOAL CHANNEL

Topics addressed here are the locations, amounts, and composite characteristics of recoverable sand deposits in Thimble Shoal Channel. The 42 locations of 1983 cores are displayed in Figure A1, along with a greatly simplified summary of uppermost materials within the Channel bottom. This classification of Channel material is extracted from the core logs, and considers only material above -55 feet MLW; a second type of material is indicated on Figure A1 only if it represents more than 25 percent of the core length.

The most extensive continuous sand body is that at the eastern Channel end. This is defined by the cores numbered 56 through 61, and is designated as Dredging Area Z on Figure 3. The Figure 4 composite grain-size distribution for this material was developed in a previous report (Table A1 in Hallermeier, Lott, and Galvin, 1984).

One other sand deposit promising as beach fill is defined by the cores numbered 50, 52, and 54, and has been designated as Dredging Area Y on Figure 3. This lies south of the Channel centerline, between stations 315+00 and 465+00. The following Table A1 summarizes computations based on available sediment analyses which result in a representative composite distribution. Figure 4 displays this Sediment Y characterization showing it to be noticeably

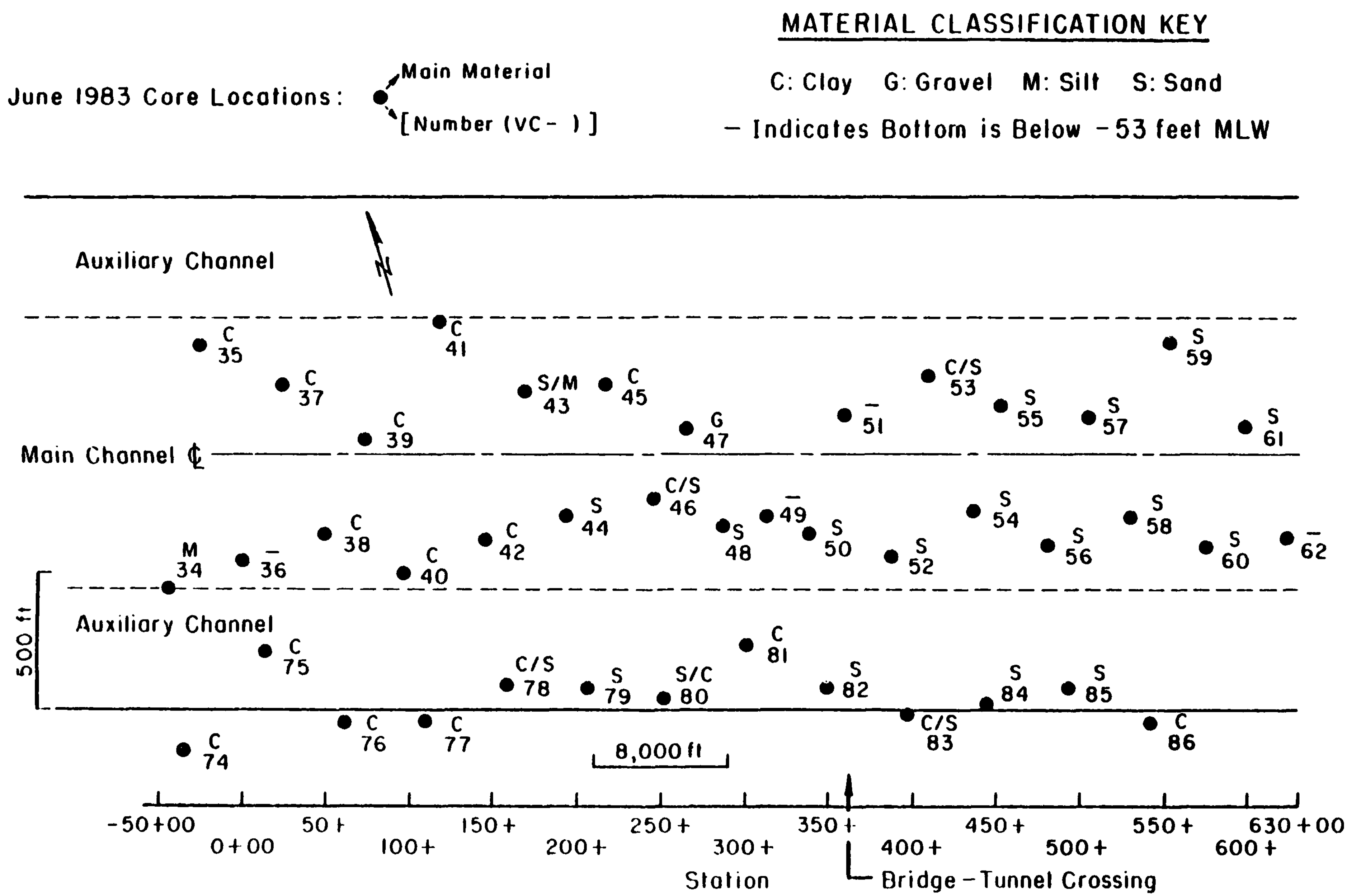

Figure A1. SUMMARY OF MATERIALS WITHIN THIMBLE SHOAL CHANNEL

coarser than Sediment Z material and thus more suitable as fill on relatively coarse beaches of West Ocean View. Granting the simplifying assumptions explained in Table A1, the amount of medium sand available above -55 feet MLW in Dredging Area Y is estimated at 850,000 cubic yards.

Computations and inferences seem less certain regarding Sediment Y than Sediment Z: the former is defined by three cores rather than six, and a distinction is introduced between the Main Channel north vs. south of the centerline. However, that distinction upon examining Figure 2 seems valid throughout Thimble Shoal Channel, except at the very eastern end, and can be tied to the main source of Channel shoaling being to the north. Further support for Dredging Area Y constituting a continuous, sand deposit is provided by neighboring cores to the west and south: core 48 slightly westward in the Main Channel shows entirely sand (but fine sand which would adversely affect the composite if included); cores 82, 84 and 85 from the south Auxiliary Channel contain almost all sand between -50 and -55 feet MLW.

TABLE A1 - COMPUTATION OF COMPOSITE GRAIN-SIZE DISTRIBUTION FOR DESIGNATED BORROW AREA Y IN THIMBLE SHOAL CHANNEL.

Information on bottom materials of Thimble Shoal Channel includes detailed log sheets providing visual description of cores, and sieve analysis curves for samples from selected core segments. Recorded water depth at each core location ties elevations within a core to the MLW datum plane. For present purposes, available information is summarized as follows: separate core strata are listed with their vertical extent and the letters describing the material according to the Unified Soil Classification System. The uppermost stratum is at the top of each list, a horizontal line shows the location of -55 ft MLW within each core, and the location and I.D. of sediment samples are indicated.

There is no direct evidence contrary to a contiguous sand deposit being revealed in the side-by-side cores numbered VC-48, -50, -52, and -54. Attention is focused on those cores as a possible additional source of beach-fill sand (outside Borrow Area Z considered previously). The summary of available information is as follows in depths of interest:

VC-48

Sample		
A →	SM	3.3'
B,C →		16.7' btm

VC-50

	SP	2.0'	I
A →	SP-SM	1.2'	II
		0.8'	
	SP-GP	0.8'	
B →	SP-SM	2.7'	
	CL	1.9'	

VC-52

A →	SM	3.4'	I
B,C →		16.6' btm	

VC-54

	SP	0.8'	I
	GP	0.2'	II
A →	SP	2.1'	III
	SP-CH	0.3'	IV
	GP	0.5'	
	SP	0.2'	
B →	CL	7.9'	

For beaches along western Ocean View, relatively coarse fill sand will be most suitable. Although all material in core 48 is classified as sand (S), descriptions are "silty fine sand" and "very fine sand and silt"; sieve analyses of samples are not available, but percentages of fines are reported to be about 35%. Such fine material is undesirable, so attention will be restricted to cores 50, 52 and 54 as an area for potential borrow.

RJH/15Mar84

Above -55 feet MLW, this leaves 7 separate strata to consider in computing a composite borrow representation. The available sieve analyses for 50A, 52A, and 54A directly represent two-thirds of 10.0 feet total core length, a propitious situation. Remaining gaps are removable by reasonable approximations:

1- The top SP layer in core 50 is described by the sieve analysis of sample B from core 79, within another SP layer. Even though these core locations are widely separated (2½ miles) and have no common absolute vertical elevation (core 79 btm is about -49 ft MLW, whereas core 50 top is about -52 ft MLW), this is deemed appropriate because of the good match in material descriptions on the core logsheets. [An alternative is to use 50A to represent the entire upper 3.2 feet of core 50; there is an exact match in verbal description, but the fact that basic classification differs, SP vs. SP-SM, causes concern by indicating some fundamental distinction between these strata.]

2- The sampled SP layer in core 54 is taken to typify the entire core segment above -55 feet MLW. That SP layer (fine to medium sand, trace of coarse gravel) appears coarser than the upper SP layer (fine sand, little fine gravel) but finer than the GP layer (fine gravel and fine sand, trace of silt), and its grain-size distribution likely lies near the middle of that for the poorly-sorted SP-CH layer (fine sand to fine gravel, clay and silt). Thus, adopting the available sieve analysis seems a fairly balanced approach to describing the unknown layers.

The overall effects of these particular assumptions can be projected to be that the resulting borrow composite underestimates both the fine and coarse fractions of recoverable materials; the grain-size distribution will appear narrower than in reality, but the center or median diameter should be realistic. A more serious problem than describing unsampled segments of available cores arises in developing a sure representation for borrow-area sediment: the large number of thin strata in cores 50 and 54, flanking the homogeneous deposit in core 52, makes it quite apparent that

Designated Borrow Area Y has great variability in sediment deposits. Additional cores seem highly advisable, to determine along-Channel diversity and to define suitable across-Channel extent of borrow (rather arbitrarily chosen as south of the centerline here).

With available information and assumptions deemed appropriate, the composite grain-size distribution for Borrow Area Y is computed:

SAMPLE \ SIEVE No:	4	10	20	40	50	70	100	140	200	FINES
	RECORDED PERCENTS COARSER BY WEIGHT IN ANALYZED CORE SAMPLES									
50A (50 II) {0.12 WEIGHT}	1	2	15	33	20	17	5	1	1	5
52A (52 I) {0.34 WEIGHT}	1	3	5	3	3	7	51.5	11.5	3	12
54A (54 I/IV) {0.34 WEIGHT}	3.5	5.5	17	33	17	15	4	1	1	3
79B (50 I) {0.20 WEIGHT}	—	—	3	15	22	31	20.5	4.5	1	3
WEIGHTED COMPOSITE	1.65	3.13	9.88	19.20	13.60	15.72	23.57	5.27	1.68	6.30
CUMULATIVE		[illegible]	14.7	33.9	47.5	63.2	86.8	92.0	93.7	100
{If 50A is used for 79B (50 I)}	1.65	5.4	17.7	40.5	53.[illegible]	[illegible]	87.1	[illegible]	[illegible]	[illegible]

so that alternative gives more coarse and very fine material.

The preferred composite appears fairly Gaussian - a straight line on probability/logarithmic paper - with interpolation giving:

D_{16} = 0.78 mm (0.36 ϕ), D_{50} = 0.278 mm (1.85 ϕ), D_{84} = 0.156 mm (2.68 ϕ).

This composite is taken to represent the area between Stations 315+00 to 465+00 in the Main Channel south of the centerline, 500 feet wide by 15,000 feet long by (10.0/3) average deposit thickness, giving 925,000 cubic yards with 850,000 being coarser than 0.1 mm in diameter and not thought very liable to handling or other rapid loss.

APPENDIX B

SAND CHARACTERISTICS ON BEACHES OF WEST OCEAN VIEW

The following plots for study sites display median and representative extreme sediment diameters: D_{50}, D_{16}, D_{84}. These have been interpolated from available results of sieve analysis at half-phi intervals. Grain diameter in phi units is plotted against location along the coast of West Ocean View, for each nominally comparable sampling station. Figures B1-B4 pertain to samples from dune, berm, foreshore, and offshore, respectively.

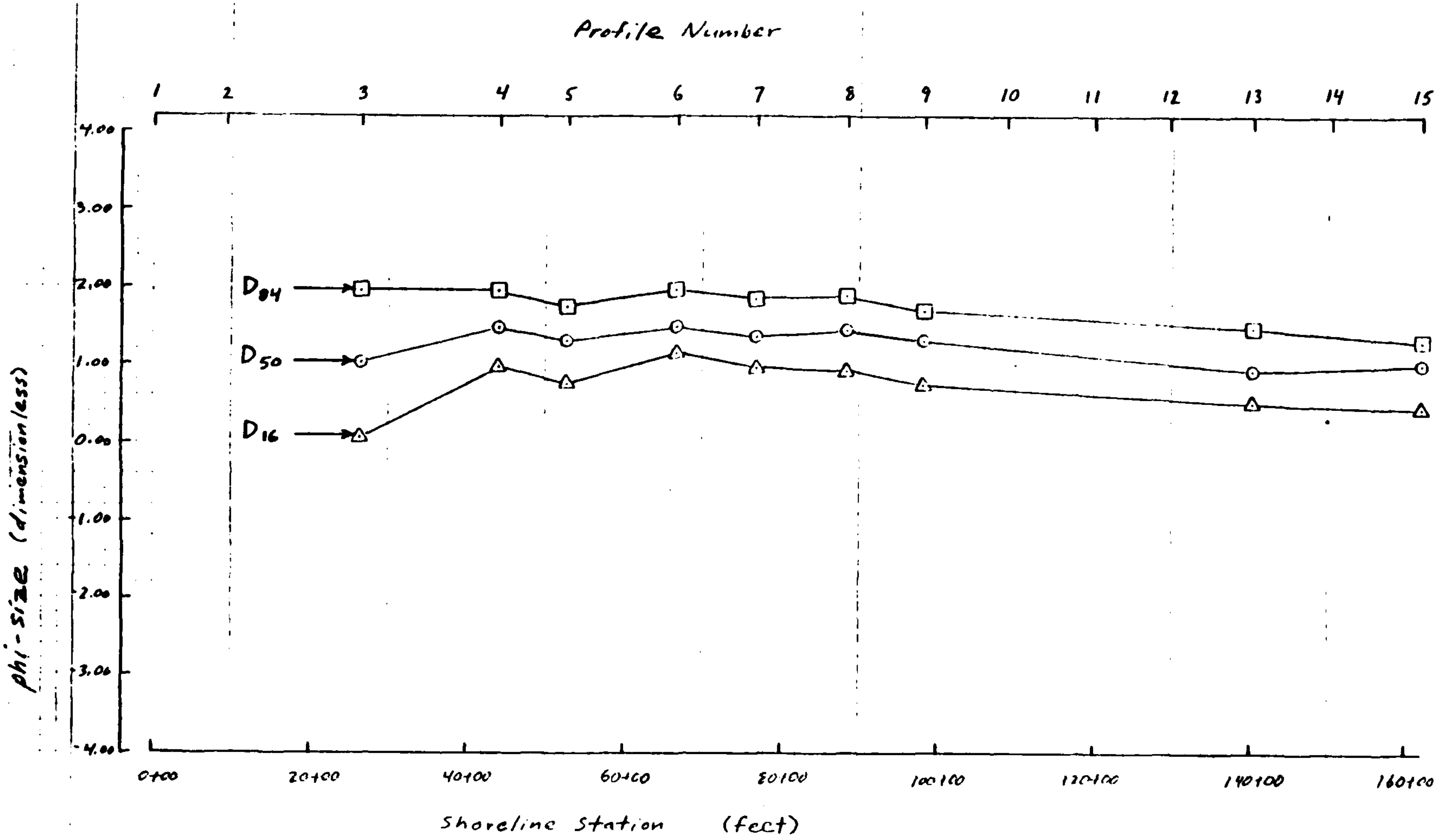

FIGURE B1. DUNE SAMPLES (A) AT WEST OCEAN VIEW

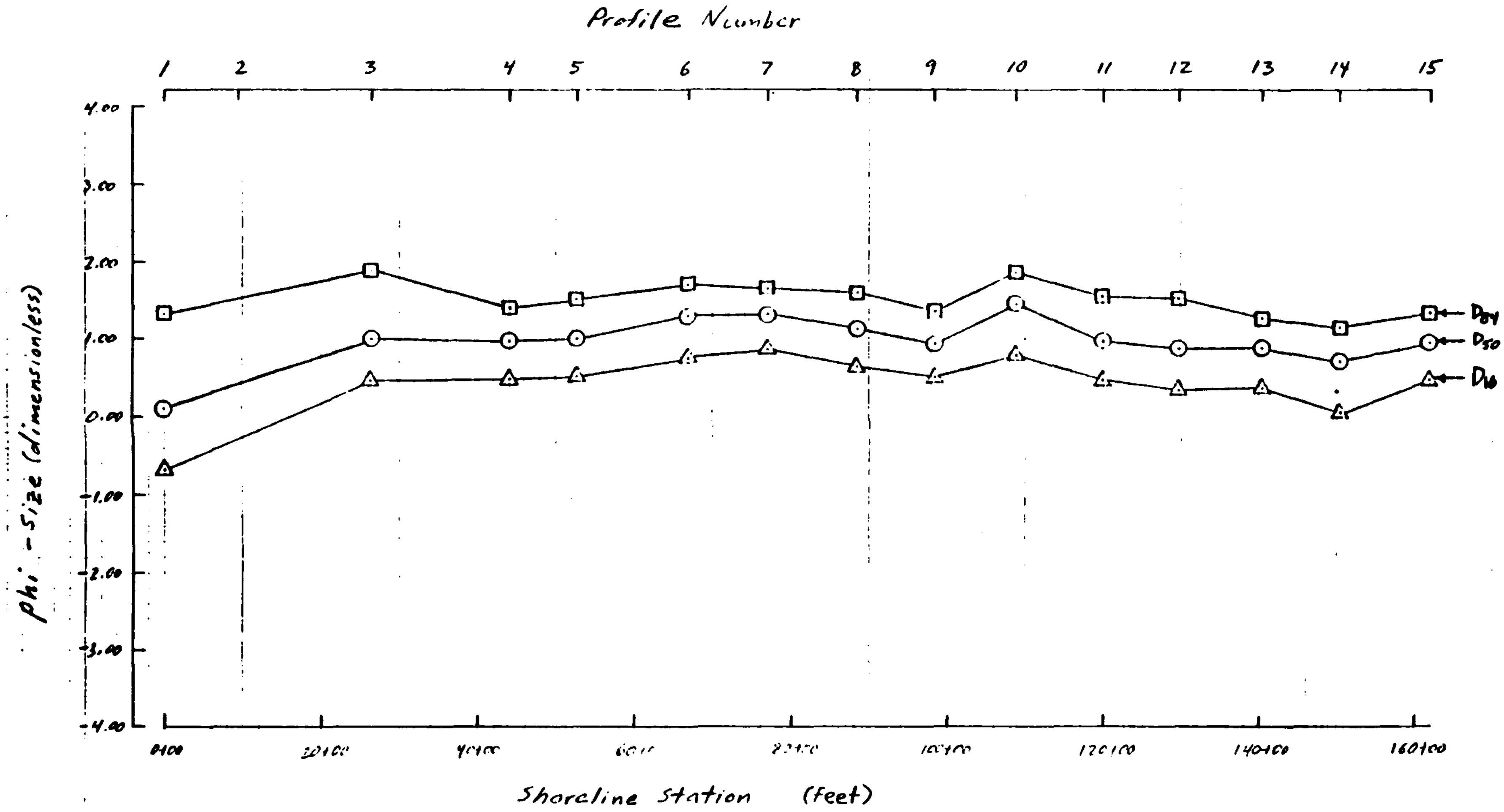

FIGURE B2. BERM SAMPLES (B) AT WEST OCEAN VIEW

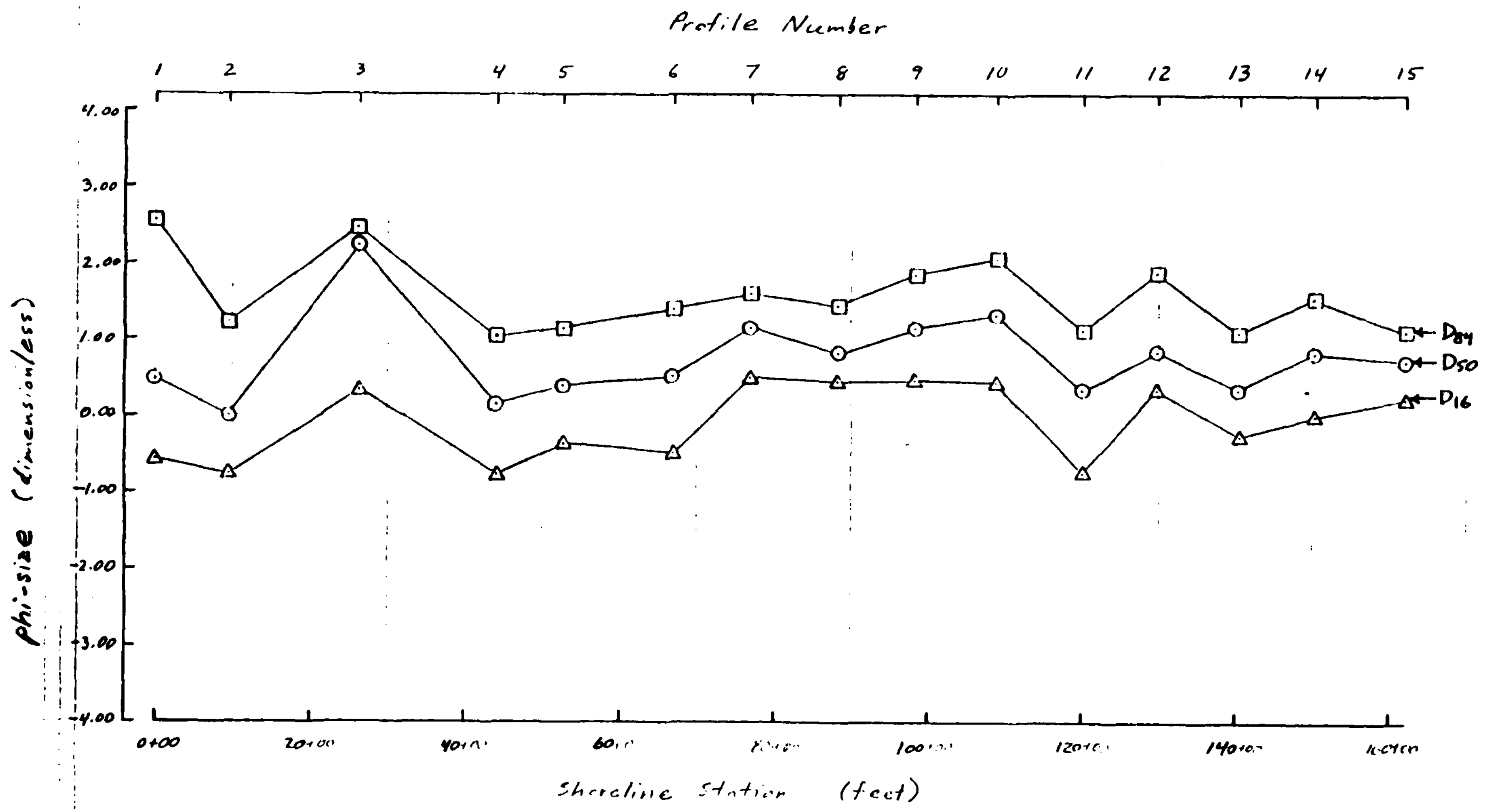

FIGURE B3. FORESHORE SAMPLES (C) AT WEST OCEAN VIEW

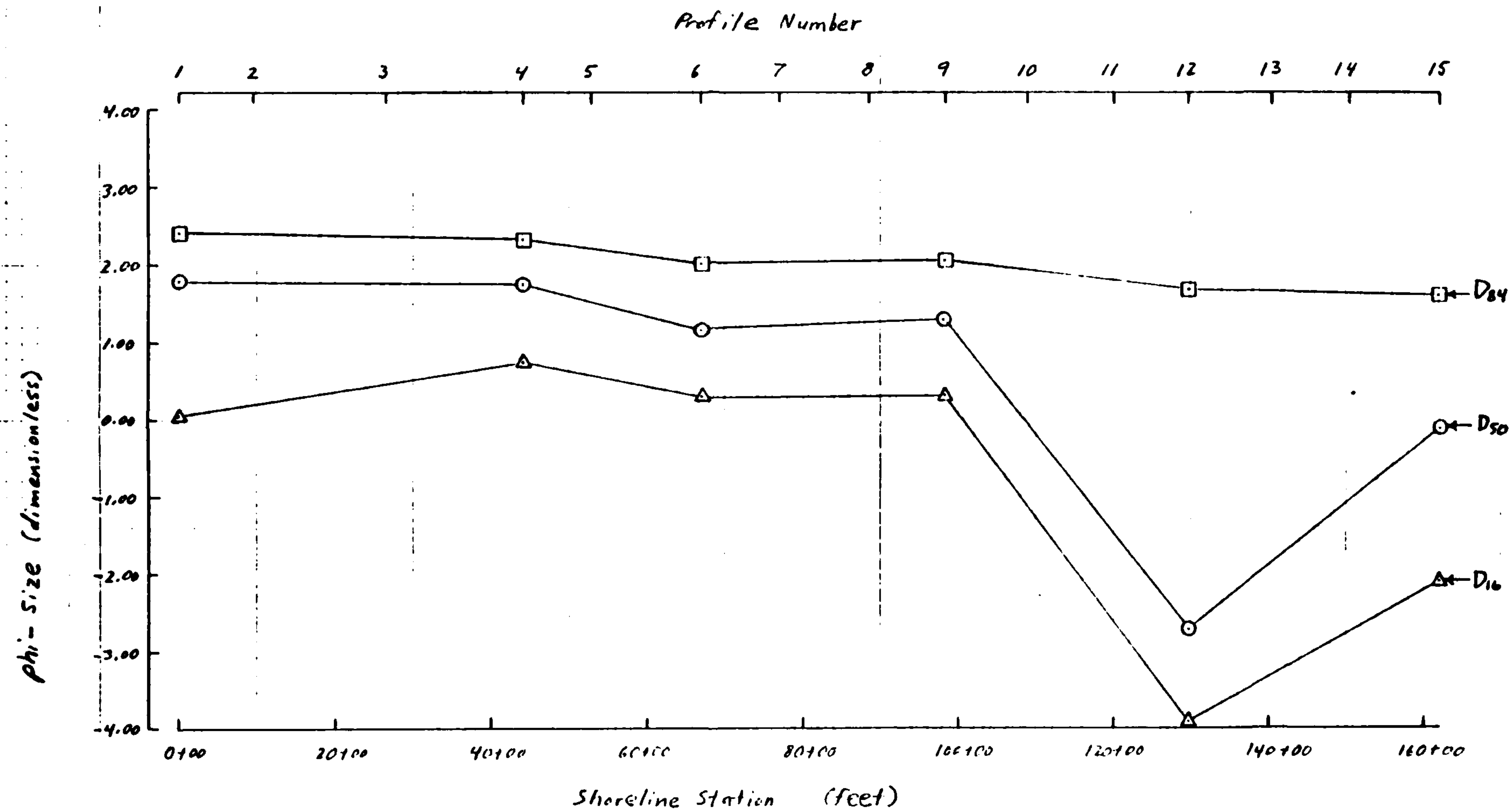

FIGURE B4. OFFSHORE SAMPLES AT WEST OCEAN VIEW

APPENDIX C

COMPUTATIONS OF WAVES FROM CHESAPEAKE BAY

The topic here is analyses regarding the exposure of sites at West Ocean View to major fetches within Chesapeake Bay. Procedures used are from Sections 3.43 and 3.61 of the 1977 edition of the Shore Protection Manual. Usual results are forecast values of significant wave height and period considering wind and wave directions, for direct use in assessing rates of littoral drift. However, the immediate aim of present efforts was to compare the Bay exposure of the study area to that at a wave-gage location on South Thimble Island of the Chesapeake Bay Bridge-Tunnel.

Figures C1 and C2 show the geometrical exposures to the Chesapeake Bay of the gage site and Willoughby Spit sites. For the Bridge-Tunnel wave gage, the central fetch radial in Figure C1 is oriented at a compass direction of about 355° and the effective fetch computation in Table C1 reveals that subsidiary fetches to either side are fairly balanced. On Willoughby Spit, sites near profile lines 3 and 10 are analyzed in Figure C2 and in Tables C2 and C3, with central radials placed near 017° in each case; near line 3 moving the central radial about 4° further east would give better balance to the fetch geometry, while the same would be accomplished near line 10 by moving the central radial about 2° further north.

Figure C3 shows the diagram used in estimating a representative water depth for the major region of Bay-wave generation. Depth along 5 east-west transects across the

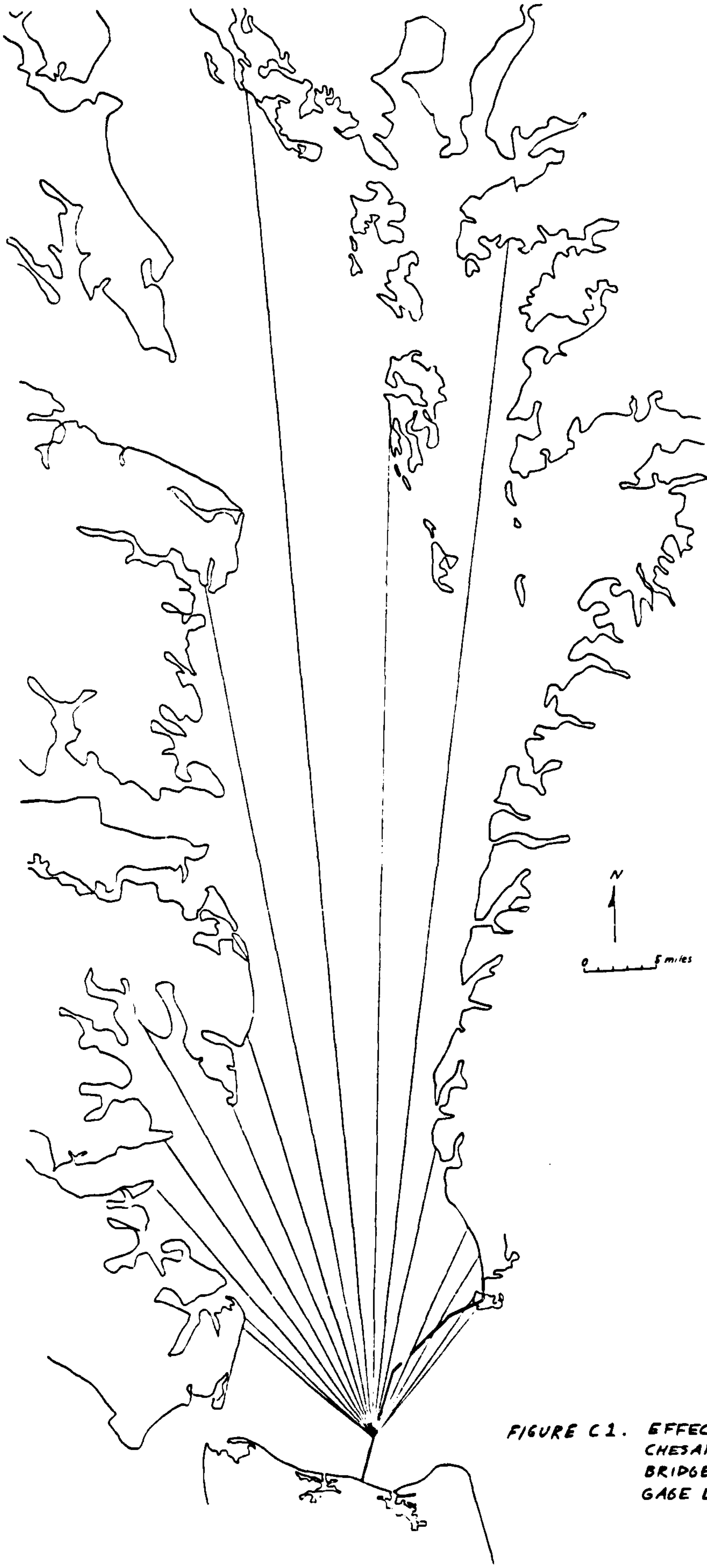

FIGURE C1. EFFECTIVE FETCH-
CHESAPEAKE BAY
BRIDGE-TUNNEL
GAGE LOCATION

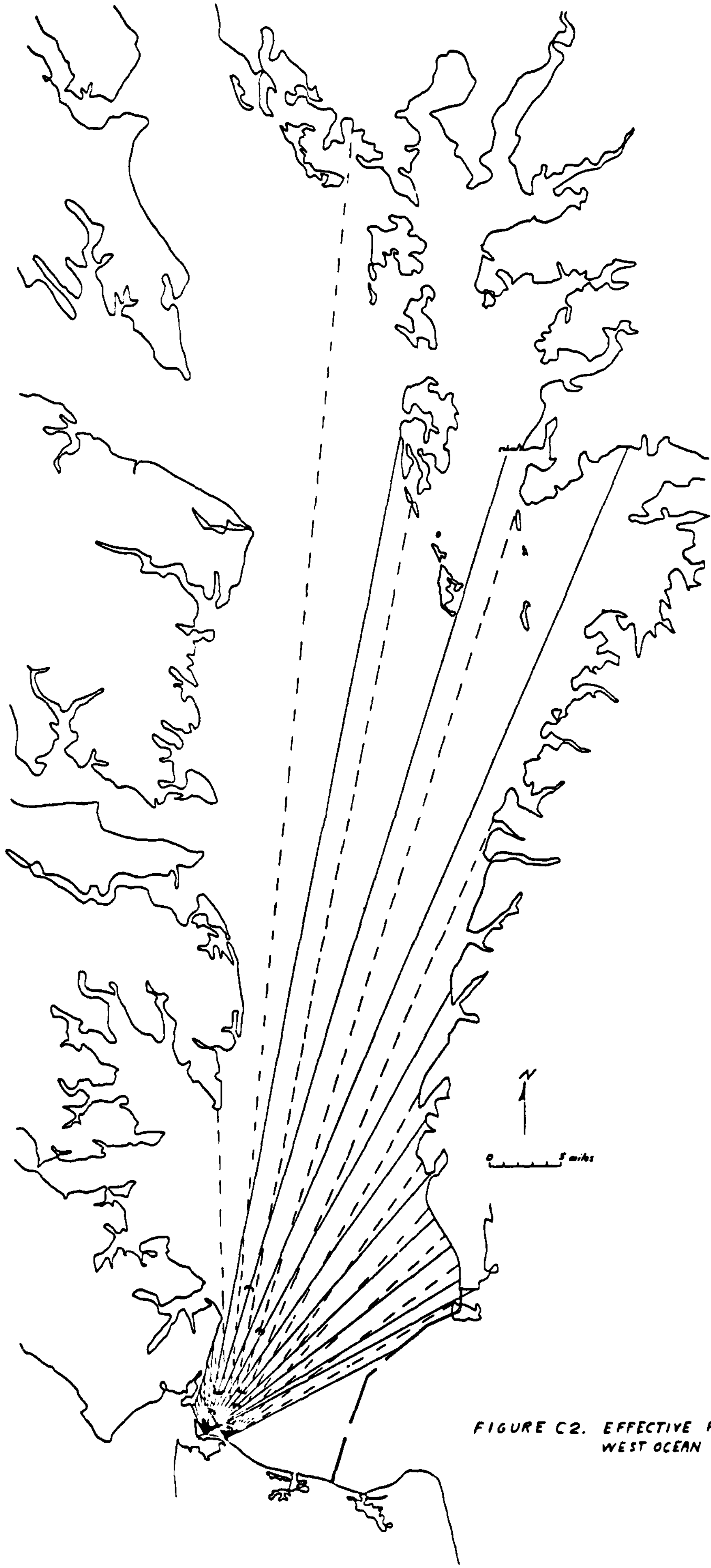

FIGURE C2. EFFECTIVE FETCH-
WEST OCEAN VIEW SITES

α	$\cos^2\alpha$	r	$X_i \cos\alpha$
42	.552	3.8	2.10
36	.655	7.3	4.78
30	.750	7.9	5.93
24	.835	10.1	8.43
18	.904	7.8	7.05
12	.957	9.1	8.71
6	.990	18.7	18.51
0	1.000	29.1	29.10
6	.990	21.4	21.19
12	.957	25.8	24.69
18	.904	6.3	5.70
24	.835	(blocked by Bridge-Tunnel)	
30	.750	4.9	3.68
36	.655	4.5	2.95
42	.552	3.7	2.04
Σ =	13.512		144.86

$$F_{eff} = \frac{\Sigma X_i \cos\alpha}{\Sigma \cos\alpha}$$

$$= \frac{144.86}{13.512} = 10.72 \text{ in.}$$

(at a scale of 1:200,000
1 in. = 3.16 statute miles)

$$F_{eff} = 10.72 \times 3.16 = \boxed{33.9 \text{ miles}}$$

EFFECTIVE FETCH CALCULATION FOR CHESAPEAKE BAY BRIDGE-TUNNEL GAGE LOCATION.
TABLE C1.

α	$\cos\alpha$	r	X_i	$X_i \cos\alpha$
42	.743	0.8	0.59	0.44
36	.809	0.7	0.57	0.46
30	.866	0.8	0.69	0.60
24	.914	1.0	0.91	0.83
18	.951	1.3	1.24	1.18
12	.978	2.1	2.05	2.00
6	.995	22.3	22.19	22.08
0	1.000	22.4	22.40	22.40
6	.995	23.5	23.38	23.26
12	.978	11.1	10.86	10.62
18	.951	8.4	7.99	7.60
24	.914	7.5	6.86	6.27
30	.866	6.8	5.89	5.10
36	.809	6.7	5.42	4.38
42	.743	6.5	4.83	3.59
Σ =	13.512			110.81

$$F_{eff} = \frac{\Sigma X_i \cos\alpha}{\Sigma \cos\alpha}$$

$$= \frac{110.81}{13.512} = 8.20 \text{ in.}$$

(at a scale of 1:200,000
1 in. = 3.16 statute miles)

$$F_{eff} = 8.20 \times 3.16$$
$$= \boxed{25.9 \text{ miles}}$$

EFFECTIVE FETCH CALCULATION FOR WEST OCEAN VIEW, VIRGINIA, NEAR PROFILE LINE 3.

TABLE C2.

α	$\cos^2\alpha$	r	$X_i \cos\alpha$
42	.552	1.3	0.72
36	.655	1.5	0.98
30	.750	1.7	1.28
24	.835	2.2	1.84
18	.904	7.2	6.51
12	.957	28.8	27.56
6	.990	20.9	20.69
0	1.000	21.2	21.20
6	.990	14.7	14.55
12	.957	8.7	8.33
18	.904	7.4	6.69
24	.835	6.7	5.59
30	.750	6.5	4.88
36	.655	6.3	4.13
42	.552	5.7	3.15
Σ=	13.512		128.10

$$F_{eff} = \frac{\Sigma x_i \cos\alpha}{\Sigma \cos\alpha} = \frac{128.10}{13.512} = 9.48 \text{ in.}$$

(at a scale of 1 : 200,000
1 in. = 3.16 statute miles)

$$F_{eff} = 9.48 \times 3.16 = \boxed{30.0 \text{ miles}}$$

EFFECTIVE FETCH CALCULATION FOR WEST OCEAN VIEW, VIRGINIA, NEAR PROFILE LINE 9.
TABLE C3.

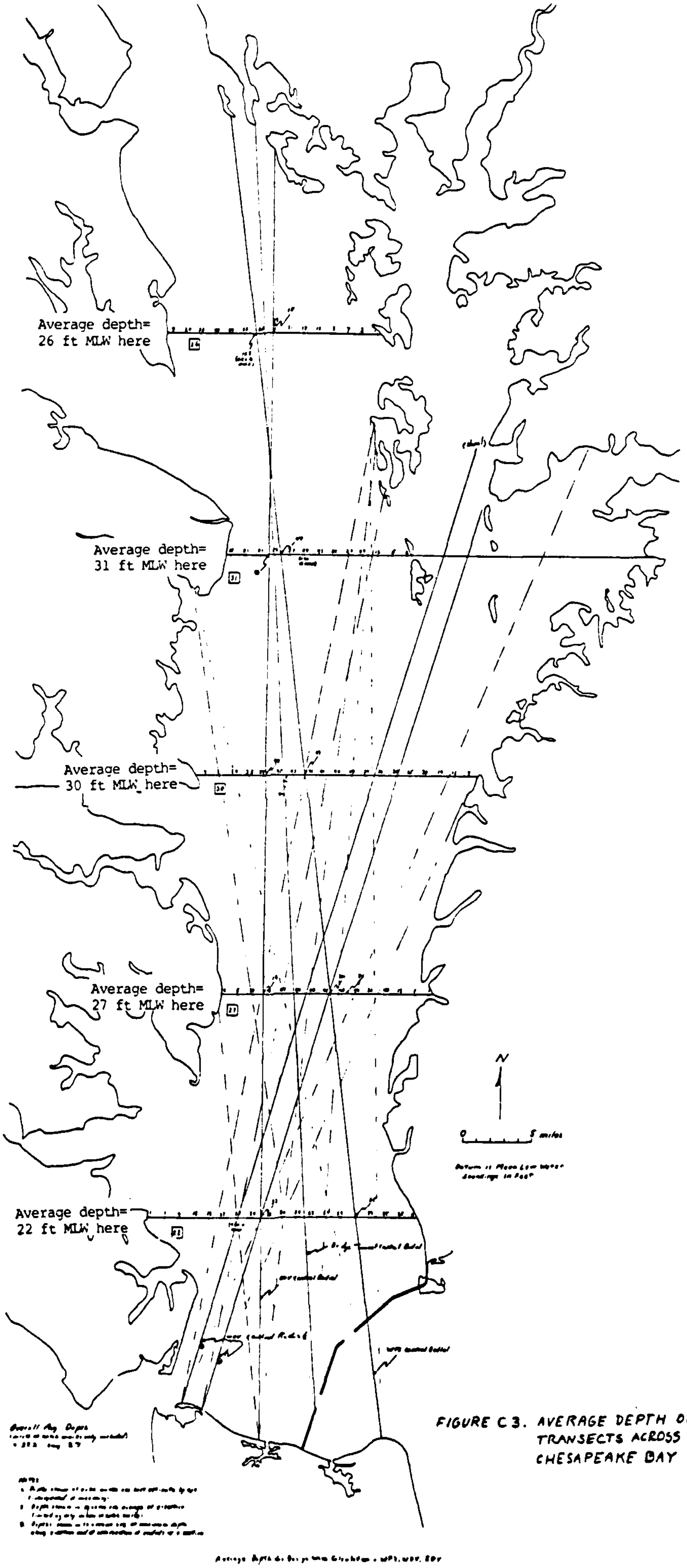

FIGURE C3. AVERAGE DEPTH ON TRANSECTS ACROSS LOWER CHESAPEAKE BAY

Bay are extracted where the central and the two adjacent radials intersect them. Mean depth of soundings for each fetch analysis is then computed. All resultant values are nearly the same: 35 feet MLW for the gage site and the line 10 Ocean View site, and 34 feet MLW for the line 3 site.

There are appreciable differences in exposure between the three sites with regard to nearby shoals, measured as extent of central radial over water depths less than 18 feet MLW: none front the gage site, about 36,000 feet lie in front of line 10, and about 49,000 feet front line 3. The shallow areas seaward of Willoughby Spit are indicated by brackets on central radials in Figure C2. These shoals do not seem significant in reducing the region of major wave generation, but large wind waves propagating towards shore will encounter appreciable bottom friction and attenuation due to agitated bottom sands, as discussed in the main report text.

Table 4 presents several wave forecasts for conditions appropriate in comparing the gage and West Ocean View sites. Those forecasts specify only that winds are approximately from the north. The differences of up to 25° in orientation of major exposure for the three sites are at most only comparable to the angular resolution (22.5°) of available wind data, so that wind direction was not specified exactly for wave forecasts.

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